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The Journal of Bone and Joint Surgery

EDITORIALS AND ANNOTATIONS

THE CLASSIFICATION OF BONE TUMOURS

It is over thirty-five years since the late Dr Codman was asked by the relatives of a patient suffering from a malignant tumour of bone, whether there were any cured cases of this condition and if so, what treatment had been adopted. Dr Codman could not answer these questions and so he was given a thousand dollars to find out. This was the origin of the Bone Sarcoma Registry of the American College of Surgeons and, as is so often the case in medical advances, it was based on a false assumption, for when the patient died at the end of 1920, he was found to have been suffering from a metastatic carcinoma from an unknown primary and not a bone sarcoma at all.

Nevertheless, this revival of collective investigational research—for it was a method of medical research advocated by Francis Bacon, and used by John Locke and the elder Heberden—inspired critical interest in bone tumours and set the example for the establishment of registries for other types of neoplasms and uncommon conditions.

In assessing prognosis and therapeutic results in any condition, one is immediately faced with problems of classification and identification, for unless one is reasonably confident that one is comparing like conditions, conclusions must be of little value. In the present issue of the Journal Thomson and Turner-Warwick report the results of a review of 179 cases of primary bone tumours, and it is of some interest and importance to consider the evolution of the classification of these tumours in the last quarter-century.

In 1922 Dr James Ewing discussed the problem of classification in the paper which contains the first account of the "endothelial myeloma," by which he is now eponymously commemorated. Ewing at that time suggested that malignant bone tumours should be classed as:

Osteogenic sarcoma	periosteal (extraperiosteal)	
	solid, medullary and subperiosteal	
	telangiectatic	
	sclerosing	
Endothelioma	angioendothelioma	solitary
	diffused	multiple
Myeloma	plasma-cell	
	lymphocytic	
	myelocytic	
	erythroblastic	

In agreement with Bloodgood's dogmatic assertions, Ewing accepted the giant-cell tumour as benign, but, with regard to osteogenic sarcoma, he felt it was unfortunate that it was necessary to distinguish the periosteal osteogenic sarcoma from the medullary variety "but the facts demand the sacrifice of simplicity in the interests of more accurate knowledge." He had found that the periosteal osteogenic sarcoma had a much better prognosis than the

medullary varieties and could readily be distinguished histologically from the periosteal fibrosarcoma.

Ewing introduced the term "osteogenic sarcoma" as a more specific term than the collective term osteosarcoma and in preference to periosteal bone sarcoma; he used it in the sense of a sarcomatous tumour derived from primitive malignant cells analogous to the osteoblast; it was, in fact, an osteoblastoma and was not used in the sense of a bone-forming tumour. The malignant cells might remain undifferentiated and induce osteolysis or, with greater differentiation, there might be "myxoid," chondromatous or osteoid stromal formation.

When the Bone Sarcoma Registry was established, Codman, on the advice of a committee of the American Pathological Society and the College of Surgeons, adopted a classification which was almost identical with Ewing's, although the periosteal fibrosarcoma was specified and an undifferentiated type of osteogenic sarcoma was also recognised; nevertheless, Codman (1924) himself questioned the desirability of subdividing the osteogenic sarcomata according to anatomical site.

The establishment of the Registry stimulated interest in this field of surgical pathology; Christensen (1925) analysed a thousand cases of bone sarcoma, mainly drawn from the Registry, studying the location, age and sex, but did not attempt any study of prognosis; and Codman (1926), after five years, could report only thirteen cases of "cured" osteogenic sarcomata and emphasised the high proportion of metastatic bone tumours which had been mistaken for primary neoplasms. Kolodny (1927) presented a detailed study of the 700 cases then in the registry, but suggested that the classification was unnecessarily complex and that a grouping into five categories, without subdivisions—osteogenic sarcoma, Ewing's sarcoma, myeloma, an unclassified residuum of sarcomata, and giant-cell tumour, was sufficient for all practical purposes. However, his views as to prognosis were not very cheering: "In bone sarcoma as in other malignant tumours, the question of therapy is still awaiting its answer. It is a strange fact that with our knowledge of minute details of the histopathology of bone tumours the progress along the practical therapeutic road is almost in the same stage that it was in some fifty years ago. As a rule, malignant bone tumours are fatal and we know of no therapeutic method to prevent death from this disease." In the following year the Bone Sarcoma Registry revised their classification, but rather than following Kolodny's suggestion of simplification, they included the periosteal and medullary fibrosarcomata under the heading of osteogenic sarcoma and added a sixth variant, the periosteal or capsular type, but omitted the undifferentiated osteogenic sarcoma.

The majority of surgeons and pathologists, both in the United States and in this country—for example, Muir (1929), Ogilvie (1929)—accepted the classification of the Registry, but there were heretics. As early as 1923 Coley (1924) had questioned Bloodgood's assertion that the giant-cell tumour was benign, and he reiterated this in 1927 and 1932, pointing out that in most cases it was possible to differentiate the benign from the malignant varieties on the basis of clinical, radiological and histological evidence; in a way, this was a return to the views of Virchow and Gross but supported by more critical clinico-pathological evidence. However, an even more important paper was that of Phemister (1930), who called attention to the existence of the chondrosarcoma which could be distinguished from the osteogenic sarcoma group both on radiological and histological grounds, and the distinction was more than justified by reason of its very much better prognosis; in this country, Platt (1932) had come to the same conclusion.

In 1931 appeared Geschickter and Copeland's monumental *Tumours of Bone* based on the Bloodgood collection of Johns Hopkins Hospital; the classification was somewhat complex as it was based on histogenesis, but the importance of this work is that, for the first time, the natural history of the individual types of tumour was correlated with therapeutic effects and embraced not merely osteogenic growths but all types of tumours arising in bone.

In 1937 a discussion on malignant tumours of bone was held at the Royal Society of

Medicine, and Scarff put forward what he described as a fairly simple classification, which clearly had affinities both with the classification of the Bone Sarcoma Registry and with that of Geschickter and Copeland. His classification was as follows:

Giant-cell tumour.
Osteogenic sarcoma.
Infiltrating chondroma.
Medullary fibrosarcoma.
Periosteal fibrosarcoma.
Myeloma.
Ewing's tumour.
Angio-endothelioma.
Chordoma.

Scarff discussed his reasons for distinguishing these types of bone tumour, some of which were well defined entities whereas others were specified for their significance in differential diagnosis.

In 1939 Ewing reported on the revised classification adopted by the Bone Sarcoma Registry. The rather curious subdivisions of osteogenic sarcoma were maintained, but the chondrosarcoma was recognised as an entity. A malignant as well as a benign form of giant-cell tumour was admitted and a system of grading was suggested, which was soon to be superseded by Jaffe, Lichtenstein and Portis's (1940) masterly paper, which not only set out a system of grading based on stromal differentiation, but emphasised that the so-called variants have little in common with genuine giant-cell tumours or with one another; these " variants " have subsequently been defined as the benign chondroblastoma (Jaffe and Lichtenstein 1942), chondromyxoid fibroma (Jaffe and Lichtenstein 1948) and aneurysmal bone cyst (Lichtenstein 1950), while the so-called giant-cell tumours of tendons and synovia are probably granulomata rather than neoplasms. This work on the giant-cell tumour, which has been accepted with few dissentients (Willis 1949) has at last placed this much debated condition in a proper perspective as a comparatively uncommon tumour of adult life.

The 1939 revised classification of the Registry also recognised the reticulosarcoma of bone, first defined by Parker and Jackson (1939) and the rather questionable liposarcoma.

One of the most important papers in relation to nomenclature and classification of bone tumours was contributed by MacDonald and Budd (1943), who reviewed the 118 cases with a five-year cure which had been classed as osteogenic sarcoma or chondrosarcoma on the Registry files. On re-examining these cases they decided that only fourteen (11·8 per cent) could be classed as osteogenic sarcoma, whereas ninety-seven (82 per cent) had been so classed in the Registry; on the other hand, they found that fifty-six (47·5 per cent) of the cases were chondrosarcoma as against the Registry classification of twenty-one (17·8 per cent) and that there were thirty-seven (31·4 per cent) of fibrosarcomata which had not been distinguished in the Registry classification from the osteogenic sarcomata. A preliminary study of the fatal cases (interrupted by the exigencies of war and so far as is known not resumed) showed that 40 per cent were osteogenic sarcoma, 40 per cent were chondrosarcoma and only 15 per cent were fibrosarcoma.

If MacDonald and Budd's conclusions are accepted (they are strongly supported by Thomson and Turner-Warwick's findings in the present number of the Journal) it is an admirable example of the dangers of drawing conclusions with regard to prognosis, etc., in relation to conditions classified in one system or another, unless the nomenclature and descriptive definitions are so clear as to leave no doubt that the categories which are being compared are truly homogeneous; it would seem very doubtful if the actual classification of cases in the Bone Sarcoma Registry can be regarded as reliable, and therefore any statistical analysis of this material must be suspect, although this in no way diminishes the immense value of the thousands of cases in the Registry when used for critical study.

The problems of identification of the various types of bone tumour has been largely resolved by the publication of Lichtenstein's monograph (1952), which not only adopts a logical and simple classification, but also provides admirable clinical, radiological and histological description of each type of tumour and furthermore includes a description of the majority of benign lesions which are liable to be confused with the more malignant tumours.

In regard to nomenclature, MacDonald and Budd did not appear to have been so critical as they were in classification, and they suggested a reversal of usage in respect of the terms osteogenic sarcoma and osteosarcoma; they proposed that osteogenic sarcoma should be a collective term to include the osteomucoid-forming tumours, the chondrosarcomata and the fibrosarcomata, and that osteosarcoma should be restricted to those tumours in which there is formation of an osteomucoid matrix; this seems undesirable as osteosarcoma is an old term whose meaning has always been non-specific, whereas osteogenic sarcoma was introduced by Ewing to mean a tumour of osteoblasts and not necessarily a bone-forming tumour, and certainly not in the vague sense of originating in bone; in the interpretation of terms, etymology should not take precedence over semantics.

Price (1952) of the Bristol Bone Tumour Registry has put forward a system of grading osteogenic sarcoma which has been used by Tudway (1953) in his study of the results of external irradiation. Price's grading is restricted to the tumours which other pathologists would class as osteogenic sarcoma and fibrosarcoma, and differentiation is based on the mitotic activity of the tumour cells; it is natural that with such a system many tumours showing great mitotic activity would have a poor prognosis, but, as both Price and Tudway admit, the correlation is often poor and this is probably due to the lack of distinction of the fibrosarcomata from the osteogenic group.

Thomson and Turner-Warwick's classification put forward in this number of the Journal appears attractively simple, for there are only five categories—osteosarcoma, chondrosarcoma, fibrosarcoma, spindle-cell sarcoma, and giant-cell tumour. However, it must be recognised that this classification is restricted to the skeletal sarcomata arising from connective tissue and excludes the malignant tumours of vascular and haemopoietic tissue, Ewing's sarcoma, chordoma, liposarcoma and the " adamantinoma " of limb bones.

The classes, with the exception of the spindle-cell sarcoma, correspond to those in the revised 1939 Classification of the Bone Sarcoma Registry and used by Lichtenstein (1952), but the particular interest of this paper is the excellent demonstration it provides that this type of classification is meaningful in relation to prognosis; it is based on all the cases seen at the Middlesex Hospital since 1925.

In regard to terminology, Thomson and Turner-Warwick follow MacDonald and Budd (1943) in misunderstanding Ewing's usage of the term osteogenic sarcoma and substitute for it the old ill-defined term osteosarcoma; if it is felt that the term osteogenic sarcoma is open to misinterpretation, then it would be quite legitimate to use the term " osteoblastic sarcoma " whose connotation could not be in doubt.

Each of Thomson and Turner-Warwick's categories has a very different natural history. The " osteosarcoma " group are the most malignant, with three-quarters of the cases fatal within a year of treatment, whereas in the chondrosarcomata there is a 50 per cent five-year survival and 40 per cent fifteen-year survival. The fibrosarcomata were intermediate in prognosis, with half the cases fatal within two years, while the spindle-cell sarcomata—a category which has not been segregated by other workers—have a curious survival pattern in that half the patients died in less than six months and the rest have survived between five and fifteen years. The giant-cell tumour group illustrates the increased gravity of this condition if the " variants " are omitted, as half the cases showed local recurrence and a quarter died from distant metastases.

The histological criteria on which the classification is based are set out very clearly and should be of great assistance to pathologists, for the follow-up results reveal that if such a classification is adopted an accurate prognosis can be given. The designation of a tumour is

significant only if the microscopist follows the rules of recognition that the authors have adopted, and it is essential to recognise, for example, that cartilaginous islands may be found in a tumour of osteoblasts and ossification may occur in a chondrosarcoma or fibrosarcoma, but in these cases they are reactions in the tumour matrix and not part of the malignant process.

With regard to grading, Thomson and Turner-Warwick have not found cytological grading of value in the osteoblastic group but they do not mention the periosteal (juxtacortical) osteogenic sarcoma (Dwinnell, Dahlin and Ghormley 1954) which is of very low malignancy and possibly corresponds to Ewing's (1922) description of the periosteal osteogenic sarcoma.

In the chondrosarcoma group, histological grading was of definite prognostic import, but no attempt was made to follow Geschickter and Copeland (1931) and Lichtenstein (1952) in distinguishing primary and secondary chondrosarcomata.

The periosteal fibrosarcoma which is not invading bone was excluded from the series, and in the fibrosarcomata grading was only of value in separating the rather uncommon, well differentiated form which has a much better prognosis. Thomson and Turner-Warwick express some doubt as to whether the spindle-cell sarcomata should be treated as a distinct type from the fibrosarcomata, even though the histological appearances are quite characteristic; they tended to occur in rather younger individuals, but it must be confessed that it would seem to the reviewer that they are probably only a variant of the fibrosarcomata.

In the giant-cell tumours, Thomson and Turner-Warwick followed the grading proposed by Jaffe *et al.* (1940) and confirm their conclusions as to the importance of stromal differentiation in the prognosis of these tumours.

It is always difficult to assess the relative merits of surgery or radiotherapy, alone or in combination, as it is necessary to know the criteria which determined the form of treatment to be adopted. All that can be said is that in the " osteosarcomata " the patients that survived three years or more had received combined surgery and radiotherapy; all the patients with chondrosarcomata who received radiotherapy alone have died, whereas 58 per cent of those who received surgery alone are still alive; in the fibrosarcomata all those treated by radiotherapy alone have died and the longest survivals are in the group treated by surgery and radiotherapy; and although the number of spindle sarcomata was small, a similar pattern of therapeutic response was observed.

In the giant-cell tumours the findings are more complex, but it seems that the worst results were obtained by curettage alone, indifferent results were obtained with radiotherapy alone, and the cases with the longest survival were treated by a combination of surgery and radiotherapy.

It is clear that if a patient nowadays asks a surgeon what is his expectation of life with a primary bone tumour, a much more accurate prognosis can be given than Dr Codman could offer thirty-five years ago, but this must be based on a critical appraisal of the clinical features, and the radiological and histological appearances. As to which form of therapy is likely to give the best result, there are as yet only general indications, and it is hoped that the study of cases in the many bone sarcoma registries that now exist will in the future also provide this answer.

A. H. T. Robb-Smith.

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OSTEOTOMY AS AN AID TO ARTHRODESIS OF THE HIP

A. G. Apley and R. A. Denham, Pyrford, Surrey, England

From the Rowley Bristow Orthopaedic Hospital, Pyrford

The painful hip continues to present a serious therapeutic problem. Arthroplasty has its uses, especially in bilateral disease, but has not proved a panacea; far too many patients have persistent pain. Arthrodesis has stood the test of time. Its advocacy may be somewhat old-fashioned, but when fusion occurs, hip pain is abolished and stability is assured. These are weighty advantages. After successful arthrodesis, if a patient complains at all, it is not of the stiffness. He may complain of symptoms in the back or knee but not in the hip itself, provided the joint is soundly fused and is in good position. With a sound arthrodesis the patient walks in comfort for long distances. He has but little limp, can sit reasonably well and, if knee flexion is good, can put on his socks and shoes; above all, he has no pain. Because a successful arthrodesis is so good, it is worth considering its disadvantages and trying to obviate them. In the following discussion only non-tuberculous hips are considered.

THE DISADVANTAGES OF ARTHRODESIS

Technical difficulties—It is difficult to ensure solid fusion; hence the many techniques that have been employed. In almost all operations, however, only two principles are involved: denuding the bone ends, and immobilising the joint.

Denuding the bone ends—Removal of the articular cartilage thoroughly from acetabulum and femoral head is liable to convert "an orange in a cup into a peeled orange in a saucer," leading to incongruity and instability (Charnley 1953).

Splintage—Internal fixation may be achieved by a trifin nail (Watson Jones 1938), by a graft, or by a nail and a graft. These internal splints can, at best, have only a small hold in the pelvis, and the leverage of the femur is so great that it causes loosening unless early bone fusion across the joint takes place; hence the necessity for additional external splintage by plaster. In a recently published series (Stinchfield and Cavallaro 1950) 119 attempted hip arthrodeses were reported; 23 per cent failed to fuse in two years; in a further 10 per cent the wound became infected or the patient died. One failure for every two fusions is not a good recommendation for an operation.

Knee stiffness and pain—Even when the bone ends have been rawed and a good hold obtained by internal splintage, it is usually felt that an external splint of plaster is essential. To be effective this plaster must include the knee and must remain on for months. In an elderly person this is liable to stiffen the knee. When the plaster is removed the patient has a struggle to put on his sock and shoe; he forces the knee to bend and puts great strain on a hip which may not yet be completely consolidated. Thus an attempt to stiffen the hip may unfortunately stiffen the knee instead. Nearly all authors emphasise the difficulty of regaining knee movement (Law 1952, Brittain 1952).

Hip deformity—Often the disease for which arthrodesis is undertaken has deformed the hip. With many techniques the question arises: should the hip be arthrodesed in deformity (which leaves the patient with some of his symptoms) or should the deformity be corrected at the hip joint (which places the fusion area under stress and compromises success)? The Brittain (1942) technique of ischio-femoral arthrodesis with osteotomy permits correction of the deformity, but has the disadvantage of requiring a plaster which encases the knee for some months. The ischio-femoral V-arthrodesis described by Howard (1950) avoids the use of plaster, but leaves the hip in its deformed position.

Back pain—It is widely believed that hip arthrodesis produces pain in the back because of the additional range demanded at the lumbar spine. It may be briefly stated here that in our series back pain—although quite common—was no more common after solid fusion than when the hip retained a considerable range. The high incidence of back pain quoted in the literature may therefore be due, at least in part, to the knee stiffness. If the hip and knee are both stiff, common actions such as putting on shoes do impose too severe a strain upon the back; but if the hip is in good position (a little flexed) and the knee bends to well beyond a right angle, back pain is much less likely to occur.

THE USE OF AN OSTEOTOMY

It was suggested by Professor George Perkins that these difficulties and disadvantages might all be overcome by a high femoral osteotomy combined with one of the standard

FIG. 1

FIG. 2

FIG. 3

Figure 1—Abductor muscles retracted upwards with greater trochanter. Figure 2—Cube of bone excised from superior joint surfaces and guide wire inserted. Figure 3—Nail driven in.

FIG. 4

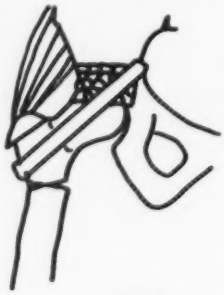

FIG. 5

Figure 4—Gap filled with bone chips and trochanter replaced. Figure 5—High femoral osteotomy to eliminate leverage.

techniques of arthrodesis. At first the osteotomy was used with a variety of methods: in some the hip joint was not opened but a trifin nail, or nail and fibular graft, were inserted across it. Recently a more standard procedure has been employed, and we call this the "Pyrford arthrodesis." The remainder of this article is devoted to describing this present technique and the results in all cases; the results without osteotomy are compared with those in which osteotomy was performed.

TECHNIQUE OF THE PYRFORD ARTHRODESIS

Exposure—The lateral approach is used, exposing the greater trochanter. The trochanter is either chiselled off and turned upwards with its attached muscles (Fig. 1), or the muscles may be divided near their insertion into the bone.

Denudation—Sometimes we dislocate the hip and denude the femoral head and acetabulum thoroughly; more often we are content merely to remove a large cube containing a piece of

each bone (Fig. 2), later replacing this cube after turning it through a right angle; or we pack the gap with bone chips (Fig. 4). The "cube" technique is adequate when the hip is already fairly stiff, but if there is much movement dislocation and denudation is the method of choice. (One case operated on nine months ago, and therefore too recent for inclusion in our series, has so far failed: the hip was very mobile and we made the mistake of using the "cube" technique.)

Internal fixation—A guide wire is inserted into the femoral neck until its tip just emerges from the femoral head. The tip is seen in the gap left by the cube of bone which has been removed (Fig. 2). A trifin nail is then threaded over the wire (Fig. 3). The nail is inserted with the hip in its deformed (adducted) position and penetrates one inch into the pelvis. Accurate measurement and placement are easy because the process is carried out under direct vision.

Osteotomy—The femur is divided transversely about half an inch below the lateral end of the trifin nail (Fig. 5). If the osteotomy were done with hammer and chisel the blows might loosen the grip of the nail, so we prefer to use an electrically operated reciprocating saw or a Gigli saw.

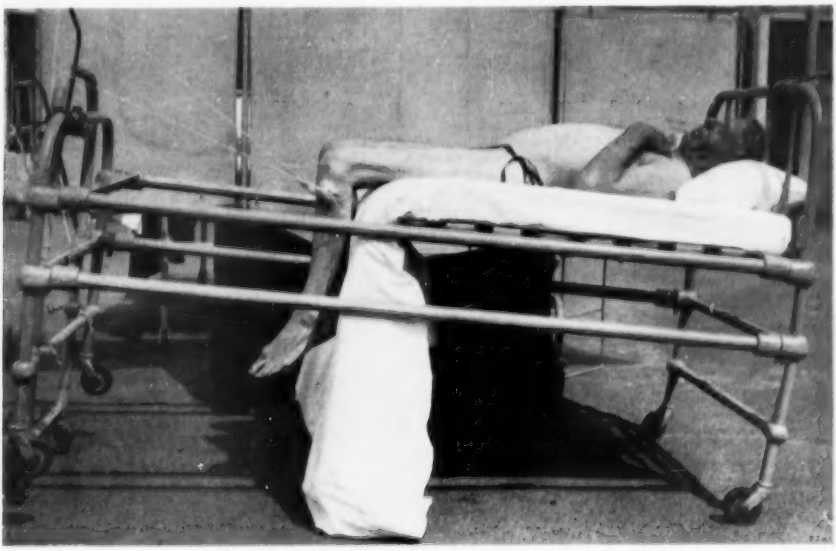

FIG. 6
Divided bed facilitates knee exercises.

Post-operative treatment—A Steinmann pin is inserted through the tibial tubercle and the patient returned to bed with 15–20 lb. traction. No external splintage is employed at this stage. Knee bending exercises are begun on the second day and practised assiduously. A divided bed (Fig. 6) relieves the hip of undue strain, but no special attempt is made to keep the osteotomy still and the patient is free to move around as much as the traction permits. After six weeks the Steinmann pin is removed. The osteotomy has usually united but is not yet consolidated, and unguarded weight bearing would be unsafe. A short hip spica is therefore applied and with this splint the patient takes weight and continues practising knee movements. As a rule the spica can safely be discarded in a further six weeks.

THE ADVANTAGES OF ARTHRODESIS PLUS OSTEOTOMY

The operation is easy to perform—Hip fusion is likely without elaborate techniques or multiple stage procedures, because during the early critical post-operative weeks the transfixing pin

has a firm hold and it is the osteotomy site that is mobile. Movement is thus transferred from a site where bony union is difficult and doubtful, to one where it is easy and probable. The operative procedure is not further complicated by the osteotomy; it is in fact easier and quicker to do an osteotomy after arthrodesis than to apply a hip spica. With the present technique our patients have not suffered from shock.

Knee stiffness is less likely than with other methods—Knee movement is preserved because the joint is exercised from the very beginning. By the time the osteotomy has joined the knee has regained mobility; there is no struggle with shoes, and the fusion area is not strained. It is likely that some of the failures of arthrodesis without osteotomy were due to our trying to force knee movement before the hip was consolidated.

Hip deformity is corrected at the osteotomy site—Since the joint is arthrodesed in its deformed position maximal bony contact is ensured and the fusion site is not strained. The final position of the limb is determined at leisure by adjustments during the first week of traction.

Back pain is less common—We believe that the explanation for this is that back pain is associated, at least in part, with knee stiffness.

RESULTS

Fifty-six patients have been followed up, the shortest time since operation being one year. One additional patient operated upon eight years ago died one week after operation. The results are summarised in Table I. By "satisfactory" we mean a hip that is solid and

TABLE I

RESULTS OF FIFTY-SIX OPERATIONS FOR ARTHRODESIS OF THE HIP

Method	Without osteotomy		With osteotomy	
	Satisfactory	Failed	Satisfactory	Failed
Trifin nail alone . . .	0	4	5	1
Nail and graft . . .	6	13	5	0
Bone rawing and nail fixation	7	3	12	0
Total . . .	13	20	22	1

painless, with a knee that can bend to beyond a right angle. There has been no selection of cases. At first a variety of methods was used without osteotomy, then in a few cases osteotomy and traction were substituted for the first six weeks in plaster, and more recently the technique just described has been employed in every case. The indications for operation, namely unilateral disease with incapacitating pain or deformity, were the same in all groups. The average age of the patients in whom osteotomy was done (53·8 years) was higher than in the other group (44·8 years).

Trifin nail alone—On four occasions we attempted to fuse the hip by a simple trifin nail, inserted under radiographic control, and with a supra-inguinal incision enabling a finger to feel that the nail penetrated the pelvis. No case was successful; but with an osteotomy in addition to the nail, five out of six were successful with even this unpromising method.

Nail and graft—In this method, as in the previous one, the joint was not opened, but a fibular graft as well as a trifin nail was inserted up the femoral neck. Again, radiographic control alone was not relied upon, and nail and graft were felt to penetrate the pelvic brim. Only six out of nineteen operations succeeded; the five additional patients in whom osteotomy was also performed all gained successful fusion.

The high failure rate with pin and graft alone is a major factor in the poor results of the entire group treated without osteotomy. Probably more would have fused had we splinted

FIG. 7
After " Pyrford " arthrodesis.

FIG. 8
Range of knee flexion.

FIG. 9

FIG. 10

Figure 9—Another case. Sound bony fusion. Figure 10—Another example showing result of operation.

the hip by a long plaster spica; in fact we only used a short spica for three to six months because we feared knee stiffness. Despite the success of combined nail, graft and osteotomy, we have abandoned this method in favour of our present technique which is equally successful and also easier.

Bone rawing with nail fixation—By this we mean that the articular surface was denuded at least in part, though not always completely. Without osteotomy seven out of ten hips were successfully fused; it is notable that this was the highest fusion rate obtained by any method without osteotomy. The ten patients in this group were mostly young and fit, so that thorough denudation, elaborate fixation and prolonged plaster were possible.

The patients subjected to osteotomy in addition to bone rawing and internal fixation were rather older, so that any selection was certainly not applied in favour of osteotomy; nevertheless successful fusion occurred in all twelve cases, and all had knee flexion to beyond a right angle. In two patients the osteotomy took longer than usual to consolidate, and the short spica was retained up to five months from operation. Typical cases are illustrated in Figures 7 to 10.

SUMMARY

1. Arthrodesis of the hip is satisfactory provided a good range of knee flexion is preserved.
2. The hip is best arthrodesed in its deformed position, and the deformity corrected by a high femoral osteotomy. Knee range can readily be retained by treating the patient on traction for the first six weeks instead of using plaster.
3. Thirty-three arthrodeses were attempted without osteotomy. Only thirteen were satisfactory. Even our best method without osteotomy gave sound fusion in only seven out of ten cases.
4. In a series of twenty-three unselected cases in which osteotomy was performed in addition to other methods, fusion occurred in twenty-two.

We should like to thank Professor George Perkins who originated the idea of osteotomy as an aid to arthrodesis, and who has given us constant help and advice. We are also indebted to Mr R. J. Furlong and Mr F. A. Simmonds who helped to develop the technique described in this paper, and some of whose cases are included in this series.

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PERONEAL SPASTIC FLAT FOOT

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The acquired deformity of peroneal spastic flat foot has posed many problems since its description by Sir Robert Jones (1897, 1916). Although radiographic anomalies in the tarsus have been emphasised in recent years (Harris and Beath 1948), there is no general agreement on their significance. Opinions on the etiology, mechanism and treatment have shown a wide divergence. On this account I have investigated thirty cases of peroneal spastic flat foot and observed the effects of a standard method of treatment over the course of two years. Among the problems that I have studied are the correlation between physical signs and radiographic findings, and the nature of the muscle pull that produces the deformity.

CLINICAL MATERIAL AND METHODS OF INVESTIGATION

Thirty feet in twenty-seven patients were investigated. Cases of generalised tarsal arthritis, which can give a closely similar picture, were excluded. Although I have not been able to elicit passive inversion when the patient was fully relaxed—a finding considered essential to the diagnosis by Sir Robert Jones—the cases have satisfied all the other diagnostic criteria: eversion deformity and pain of recent onset with free ankle movement, but with resistance to inversion by tight tendons on the outer side of the tarsus. Patients with a long history of flat foot with increasing pain and generalised stiffness of the tarsus have been excluded. Patients with bilateral deformity but unilateral symptoms are included as one case. In the clinical investigation I have taken into account the height and weight, build, psychological make-up, age, length of history and mode of onset, the posture of the foot and state of the arch before treatment, the degree of wasting of the leg, and the presence or absence of other neurological changes. The erythrocyte sedimentation rate and the differential sheep-cell agglutination test have been performed to try to pick up cases of early rheumatoid arthritis. Note has been made of the tendons that appeared, clinically, to be responsible for the deformity. Antero-posterior and lateral radiographs, oblique tarsal views (Seddon 1932) and the posterior axial view favoured by Harris and Beath (1948) have been obtained. Finally, fifty feet from normal individuals aged between thirteen and seventeen have been examined clinically and radiographically to assess the frequency of anomalies of this type in the population.

Additional investigations were undertaken in some cases in which the foot relapsed after treatment, and in some showing particularly striking clinical features. Electromyography was carried out in two cases, using surface and needle electrodes. The lateral compartment of the leg was explored under local anaesthesia in three patients to determine visually which muscle-tendon unit was responsible for the deformity. When the peroneus brevis seemed to be largely responsible its nerve supply was crushed, leaving the nerves to the other evertors intact. The so-called reflex spasm was studied by injecting the sinus tarsi with anaesthetic solutions, and in the course of fusion operations material was taken for histological examination.

In all cases the foot was examined under anaesthesia to assess the degree and rigidity of the eversion. A walking plaster was then applied with the foot inverted as far as possible and retained for three months, after which the range of active and passive movement was determined. Thereafter treatment has been by physiotherapy, sometimes with lateral steels and shoe alterations for the rest of two years. When subtalar and midtarsal arthrodesis was required it was undertaken at the end of the two-year period.

TABLE I

Clinical Details and Results in Thirty Cases of Peroneal Spastic Flat Foot

Foot number	Side	Age (years)	Sex	Occupation	Length of history	First symptom	Injury at onset	Neurological signs	E.S.R. (Wintrobe)	Radiography			Condition at manipulation	Condition after 3 months in plaster	Result at 1 year	Result at 2 years	Operation required
										Calcaneo-navicular bar	Talo-calcaneal bar	Other findings					
1	Right	15	M	Bricklayer	1 year	Pain	No	Nil	8	Nil	Nil	Articulation between lateral malleolus and calcaneum	Rigid	Rigid. No pain	Rigid and valgus. Slight pain	—	Yes
2	Right	13	M	School	3 months	Pain	No	Nil	11	Complete bar	Nil	Nil	Freely mobile	Freely mobile	Relapse at 6 months. Pain and deformity	Severe disability	Yes
3	Left	13	M	—	1 month	Pain	No	Nil	—	Synchondrosis	Nil	Nil	Freely mobile	Freely mobile	Mobile. Symptomless	No valgus but pain on use	—
4	Left	24	M	Warehouse	1 month	Deformity	Yes	Nil	18	Nil	Nil	Nil	Freely mobile	Freely mobile	Freely mobile	Slight ache. Movements normal	—
5	Right	17	M	Mechanic	3 months	Pain	No	Nil	2	Synarthrosis	Nil	Nil	Freely mobile	Freely mobile	Limited inversion. No pain	As at 1 year	—
6	Right	14	M	School	1 year	Deformity	Yes	Wasting	8	Anterior prolongation	Nil	Nil	Rigid	No spasm or pain. Still valgus	Valgus but no symptoms	Slight pain. Cannot run	Yes
7	Left	23	M	Decorator	2 years	Pain (tibia)	Yes	Nil	3	Nil	Nil	Nil	Freely mobile	Freely mobile	Valgus, spasm and slight pain	As at 1 year	—
8	Right	13	M	School	Many years	Pain	No	Nil	2	Nil	Nil	Mild midtarsal lipping	Fully mobile after tearing adhesions	Active inversion limited. No pain	Limited inversion. No pain	Valgus. Slight pain.	—
9	Left	17	M	Butcher	3 years	Pain	No	Nil	21	Nil	Nil	Nil	Freely mobile	Active inversion limited. No pain	Limited inversion. No pain	As at 1 year plus slight pain	—
10	Left	17	M	Dairyman	3 years	Pain	Yes	Nil	4	Nil	Nil	Gross midtarsal lipping	Freely mobile	Freely mobile	Valgus, spasm. Slight pain	Severe pain	Yes
11	Left	16	M	Clerk	4 months	Pain	No	Nil	3	Nil	Nil	Nil	Freely mobile	Freely mobile	Freely mobile	Freely mobile	—
12	Left	38	F	Cashier	3 years	Pain	Yes (Pott's fracture)	Nil	12	Nil	Nil	Accessory tarsal navicular	Fully mobile after tearing adhesions	Freely mobile	Freely mobile	Freely mobile	—
13	Right	13	F	School	2 months	Pain	No	Nil	26	Nil	Uncertain	Porosis	Fully mobile after tearing adhesions	Freely mobile	Limited inversion. Slight pain	As at 1 year	—

14	Left	10	M	School	4 years	Pain	No	Nil	2	Nil	Nil	Vertical talus	Freely mobile	Active inversion limited. No pain	Limited inversion. No pain	As at 1 year	—
15	Right	26	M	Engineer	8 years	Pain	No	Nil	4	Complete bar	Nil	Nil	Rigid	Rigid	Rigid and painful	As at 1 year	—
16	Left	39	F	Housewife	1 year	Pain	No	Nil	6	Nil	Probably	Midtarsal lipping	Rigid	Rigid	Rigid but no pain	Rigid. Slight pain	—
17	Left	14	M	School	6 months	Pain	No	Nil	8	Nil	Nil	Accessory tarsal navicular	Freely mobile	Slight limitation active inversion	Limited inversion. Slight pain	As at 1 year	—
18	Right	18	M	Postman	3 years	Pain	No	Nil	4	Nearly complete bar	Nil	Beaking of talus	Fully mobile after tearing adhesions	Rigid. Less pain	Rigid. Slight pain	As at 1 year	—
19	Left	16	M	Scaffolder	6 months	Pain	Yes	Nil	6	Nil	Nil	Nil	Fully mobile after tearing adhesions	Freely mobile	Limited inversion. No pain	As at 1 year plus slight pain	—
20	Right	13	F	School	3 months	Awkward gait	No	Nil	6	Approximation of bony angles	Nil	Nil	Freely mobile	Freely mobile	Relapse at 6 months. Manipulation and replaster	Freely mobile. No pain	—
21	Left	13	F	—	3 months	Awkward gait	No	Nil	6	Nil	Nil	Nil	Freely mobile	Freely mobile	Freely mobile	Freely mobile	—
22	Right	13	F	Nil	1 month	Deformity	No	Nil	4	Nil	Nil	Nil	Freely mobile	Freely mobile	Freely mobile	Limitation of inversion. No pain	—
23	Right	16	M	Butcher	2 months	Pain	Yes	Nil	2	Nil	Nil	Marked porosis	Freely mobile	Slight limitation active inversion	Limitation. Slight pain	As at 1 year	—
24	Right	14	M	School	3 years	Deformity	No	Nil	2	Nil	Yes	Congenital equinus of talus	Rigid	Rigid. No pain	Rigid. Slight pain	As at 1 year	—
25	Right	11	F	School	1 year	Pain	No	Nil	8	Synchondrosis	Nil	Nil	Fully mobile after tearing adhesions	Rigid but no valgus	Valgus. Slight pain	Valgus. Severe pain	—
26	Left	25	M	Joiner	3 years	Pain	No	Nil	2	Nil	Yes	Midtarsal lipping	Rigid	Rigid. No pain	Rigid valgus. Slight pain	As at 1 year	—
27	Right	10	F	School	6 months	Pain	Yes	Nil	8	Synchondrosis	Nil	Nil	Freely mobile	Freely mobile	Slight valgus. Slight pain	Valgus spasm and pain	—
28	Left	10	F	—	9 months	Pain	Yes	Nil	8	Complete bar	Nil	Nil	Fully mobile after tearing adhesions	Slight limitation active inversion	Limited inversion. No pain	Limited inversion. Slight pain	—
29	Right	14	F	Domestic service	1 month	Pain	No	Yes (see text)	6	Nil	Nil	Nil	Freely mobile	Slight limitation active inversion	Freely mobile	Hysterical inversion deformity	—
30	Right	15	M	Fitter	1 year	Pain	Yes	Yes (see text)	14	Nil	Yes	Midtarsal lipping	Rigid	Rigid. Less pain	Rigid. Slight pain	As at 1 year	—

OBSERVATIONS AND DISCUSSION

Table I gives a general account of the patients and of the clinical and radiological findings.

Peroneal spastic flat foot is rare. Harris and Beath (1947) found seventy-four cases among 3,619 Canadian army recruits, an incidence of 2 per cent. The condition is seldom found in patients over the age of twenty. In my series there were six patients over twenty; in these, symptoms dated from a period of unusually severe exertion. In general, the patients are in late adolescence or have recently acquired a more strenuous occupation. The records of the height, weight and build show that stature plays no particular part. As to general intelligence, excluding one Mongol there were eight patients with mental backwardness, an incidence higher than would be expected in a group of this size. The commonest initial symptom was pain, and it was unusual to obtain a history of recent injury. The foot generally assumed a valgus position, but the arch itself was seldom altered. There were signs of neurological disease in one case, whereas Haberler and Winkler (1934) found pyramidal signs in ten out of forty-two cases. When any suspicion of hysterical manifestations was aroused the help of a psychiatrist was sought, and in one case this diagnosis was confirmed, the patient later developing a hysterical inversion deformity.

Radiographic findings—The incidence of developmental tarsal anomalies in the general population is unknown. Harris and Beath (1947) found a calcaneo-navicular bar in one of 3,619 army recruits but they did not assess the frequency of talo-navicular bridge. Pfitzner (1896) examined 840 foot skeletons and found a calcaneum secondarium in 1 per cent. The fifty feet from normal adolescents radiographed as a control series in this investigation showed no bony abnormality.

In the present series of thirty abnormal feet, nine showed a calcaneo-navicular anomaly varying in degree from a prolongation of the anterior process of the calcaneum to a complete bony bar. Four showed the talo-calcaneal bridge described by Harris and Beath (1948). Two of these four showed mid-tarsal lipping, said to confirm the presence of this developmental anomaly.

Other radiographic abnormalities included: An abnormally high ridge of bone on the superior surface of the navicular adjacent to its articulation with the talus (one case); an abnormal joint between two bony prominences below the lateral malleolus (one case) (Fig. 5); accessory navicular bone (two cases); vertical talus (two cases); marked osteoporosis (two cases). The presence of a talo-calcaneal bridge was presumed but could not be definitely established in one other case.

The remaining eight feet showed no radiological abnormality. Tracings of the relevant part of the tarsal radiographs are shown in Figure 1.

The inter-relation of physical signs and tarsal anomalies—It is upon this aspect of the problem that there has been a wide variance of opinion. Harris and Beath (1948) wrote: "We shall show that most cases of peroneal spastic flat foot are due to tarsal anomalies." This statement was based upon the study of seventeen cases. In twelve there was a talo-calcaneal bridge, and in three a calcaneo-navicular bar; the remaining two patients had tarsal rheumatoid arthritis. These authors suggested that in cases due to tarsal anomalies the feet have always been flat, and that the history dates back to early childhood.

On the other hand Seddon (1932) wrote: "The interference with the action at this [midtarsal] joint resulting from the presence of the calcaneo-scaphoid bar explains the clinical picture." He gave an explanation for the fact that although the anomalies are developmental, the symptoms only appear in late childhood. He suggested that in childhood the interference in smooth action of the midtarsal joints is compensated for by their cartilaginous covering, but at twelve to fourteen this cartilaginous covering is lost, and with it the compensation. This view accords with other authorities in suggesting that the presence of a bony anomaly is sufficient to account for the symptoms and signs, the inference being that the anomaly is an incorrigible bar to inversion.

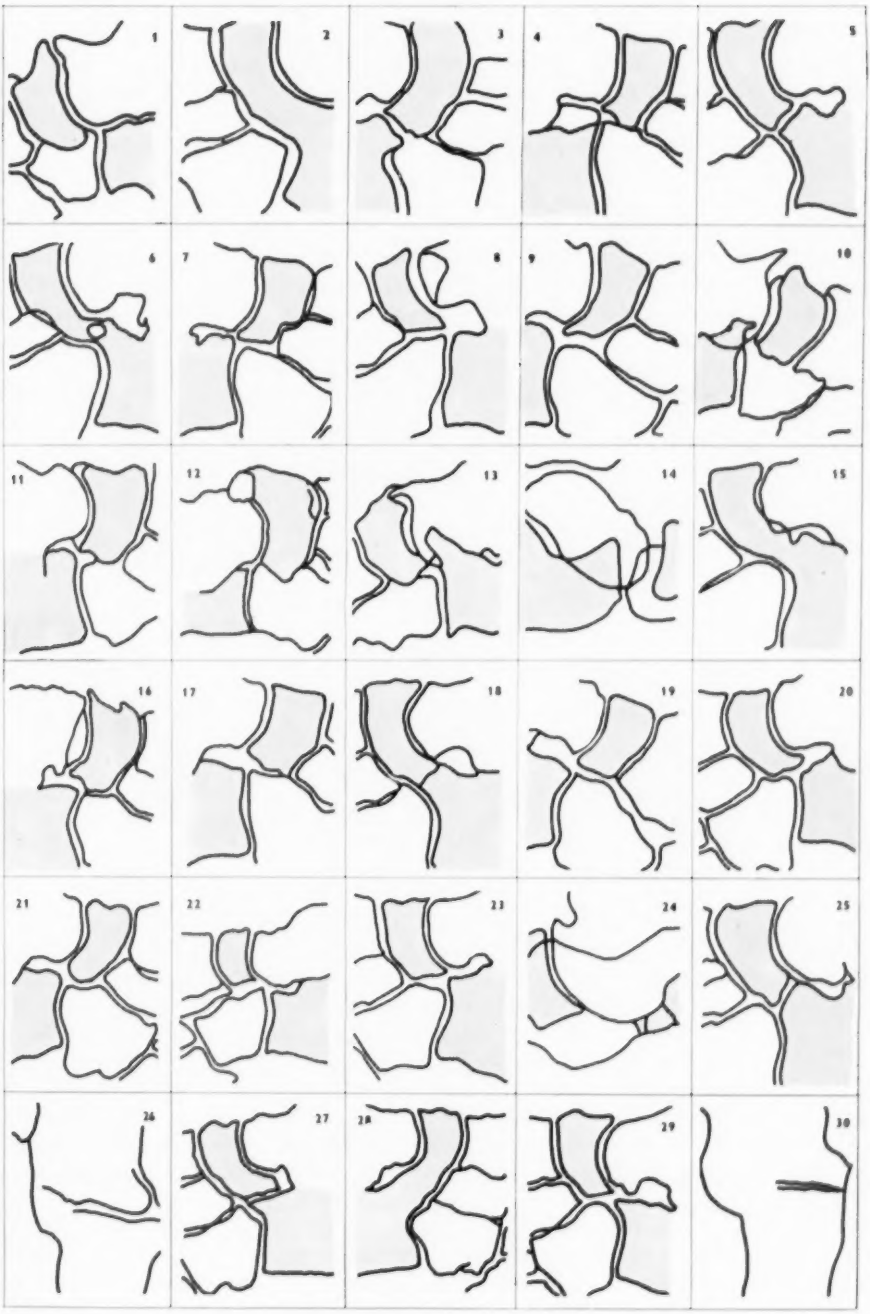

FIG. 1

Tracings from radiographs showing the relevant parts of the tarsus of each case. The navicular and the calcaneum are shown stippled for clarity. In cases 4, 7, 9, 11, 19, 21, 22 and 29 there was no radiological anomaly.

All the feet of the present series were manipulated under anaesthesia, sometimes with the use of a relaxant. This has produced one of three results: 1) The foot has fallen without effort into the neutral position, from which it could easily be placed into full inversion (sixteen cases); 2) the foot has assumed a position of less inversion, and full inversion has been obtained only with force, accompanied by the tearing of adhesions (seven cases); 3) the foot has remained in a position varying between neutral and the pre-anaesthetic state (seven cases).

Of the sixteen feet in which full inversion was easily obtained, four had the type of calcaneo-navicular anomaly usually considered to indicate permanent incorrigible rigidity. Two others had radiographic changes which, if manipulation had not been tried, would have been thought sufficient to account for the clinical condition. The remaining ten included the eight with normal tarsal architecture and two with minor findings of doubtful significance.

FIG. 2

Photomicrograph (×75) of the synovial membrane of the posterior talo-calcaneal articulation of Case 10. The villi show mucoid change. There is no evidence of inflammation.

Of the seven feet in which full inversion could be reached after the tearing of adhesions, three possessed tarsal anomalies that would have suggested complete rigidity. The seven feet showing absolute rigidity showed radiographic changes of varying type and degree.

Thus there was no constant relationship between the degree of rigidity and the degree of radiographic abnormality, a findin. opposed to that of Seddon (1932), Webster and Roberts (1951), and others. This series shows that the clinical picture of peroneal spastic flat foot can be seen in feet with or without tarsal anomalies. Rigidity of the foot under anaesthesia indicates a severe developmental anomaly, but mobility does not necessarily imply a normal tarsal skeleton.

The irritable focus hypothesis—Lapidus (1946) studied published opinions on the origin of the reflex chain leading to spasm. He described dissections in which the interosseous talo-calcaneal ligament was found to be slack in eversion, and suggested that this anatomical finding " provides a logical explanation for the exclusive tendency of the pronators to become spastic." He suggested that the causative lesion was either traumatic or inflammatory. No writer has found any convincing evidence of a true inflammatory lesion in or near the interosseous ligament, and at present it seems unwise to incriminate the ligament solely on

account of its convenient anatomical properties. During the course of subtalar and midtarsal fusions which became necessary in four of my cases, no evidence of an inflammatory or traumatic lesion was found. Figure 2 shows the histology of the synovial membrane of the posterior subtalar joint in one case, and apart from some mucoid degeneration, presumably due to lack of use, no abnormality is seen.

Abolition of the spasm after the injection of local anaesthetic into the sinus tarsi would suggest that the afferent impulses arose there, but, although I have attempted this in six cases, I have not succeeded in producing any result, nor have I witnessed any benefit from the attempts of others.

The reflex spasm hypothesis—Harris and Beath (1948) were the first to throw doubt on the concept of reflex muscle spasm as the cause of the deformity. They suggested that the "peronei" had undergone adaptive shortening. My studies with these feet under anaesthesia have not confirmed this supposition, and I was able to get full inversion without force in sixteen of the thirty feet. Our knowledge of reflex muscle spasm is incomplete, but the electromyograph can be used to indicate whether the increased tension in a muscle is due to organic contracture or to stimulation from its motor nerve. In the former the recording will show silence at rest, whereas in the latter it will show sustained motor unit activity. I made recordings, using surface electrodes and needle electrodes, from the peroneal muscles in two of my cases. In both full inversion under anaesthesia had been obtained, so organic shortening could not be incriminated, and the recordings obtained showed no increase in motor unit activity—a totally different picture from that produced by muscle spasm seen elsewhere. In both these cases the outer compartment of the leg was opened in order to be certain that the needle was in the intended spot. Although there was an increase of tension of the peroneus brevis in these cases, the electromyograph showed no motor unit activity. If this holds good for all cases, we are dealing with a condition in which a muscle-tendon unit can show an increase of tension without either organic shortening or a volley of contractile impulses arriving along its motor nerve. It may be that this increase in tone in a muscle belongs to the class of phenomena (attributed to passive elastic tension) mentioned by Clemmesen (1951) in which the tone is produced by changes in local muscle chemistry quite independent of its nerve supply.

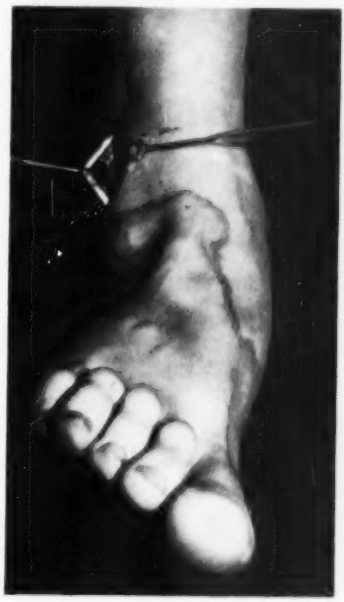

FIG. 3

Case 24—Exposure of the peroneal tendons under local anaesthesia. The deformity is well marked. The hook is round the tendon of peroneus longus. It is not unduly tight. Peroneus brevis beneath this was in a state of increased tension, and could not be withdrawn through the wound.

On the other hand, the needle electrode electromyograph in my hands is capricious, and the failure in my two cases to find any electromyographic evidence of reflex spasm may be due solely to technical difficulties; so on this slender evidence it would be unwise to swing away from the muscle spasm explanation favoured by other writers in this field.

Associated findings—Several other observations have been made in the course of the further investigations mentioned earlier.

The muscles responsible—Previous workers have stated that although other muscles play a part in the production of the deformity, the peronei are the main deforming agents. There has been a wide assumption that, since the peroneus longus and peroneus brevis lie in the

same anatomical compartment of the leg, their function as evertors at the midtarsal and subtalar joints is a like one. From dissections of the foot and from observations on other foot conditions it has been noted that the peroneus brevis is the stronger evertor and that the peroneus longus pronates the forefoot, flexing the first metatarsal segment, and only secondarily producing eversion of the whole foot. In many cases of peroneal spastic flat foot all muscles capable of exerting an evertor action are seen to be in a state of increased tension. In some cases, however, it has been my impression that clinically the peroneus brevis has been producing the deformity, the peroneus longus being normal; and the view that the "peronei" are responsible is false. I have explored the muscles in three cases under local anaesthesia to examine the tone in the two peronei. In these cases the peroneus longus was not unduly taut, but the peroneus brevis tendon was very tight. For instance, it was possible to withdraw the longus tendon on an aneurysm needle (Fig. 3), which was not possible with the brevis. This point has been investigated in only three cases, but, taken with the fact

FIG. 4

Case 18. Marked lateral rotation at the hip. Right peroneal spastic flat foot of eighteen months' duration. The patient is under anaesthesia.

that the nature of the deformity does not seem to be one characteristic of peroneus longus overaction, it suggests that in many cases it is the brevis that is contributing mostly to the deformity.

Lateral rotation of the whole limb—It was noticed in six cases that if an anaesthetic was given with a relaxant, and the two big toes were held together and then released, the normal leg would roll out and finally assume a position of about 30 degrees' lateral rotation at the hip. The leg having the peroneal spastic flat foot would fall immediately into 90 degrees' lateral rotation. This limb showed a limitation of movement by soft-tissue contracture at the hip joint. The presence of this phenomenon under relaxant drugs precludes the possibility of its being due to lateral rotator spasm, and it is suggested that as the gait of these patients is one of habitual lateral rotation at the hip, there is adaptive shortening of the soft tissues in this region (Fig. 4).

Accessory tarsal articulation—A separate articulation between the inferior aspect of the lateral malleolus and a facet on the lateral aspect of the calcaneum was seen in one case (Fig. 5) and the joint was explored. It contained a synovial cavity which did not communicate with the synovial cavity of the ankle or subtalar joint. Forced inversion opened this joint.

Exploration of the sinus tarsi and its environs in another case disclosed that, although

there was an extensive calcaneo-navicular anomaly and the hindfoot was rigid even under anaesthesia, this anomaly was not the sole factor limiting inversion. Two strong ligaments were seen passing from the supero-lateral aspect of the calcaneum to the lateral side of the neck of the talus (Fig. 6). Between them was an unimportant synovial fringe. The stouter

FIG. 5

Case 1—Accessory articulation between the lateral malleolus and a tuberosity on the lateral aspect of the calcaneum. The accessory joint has been opened by inversion.

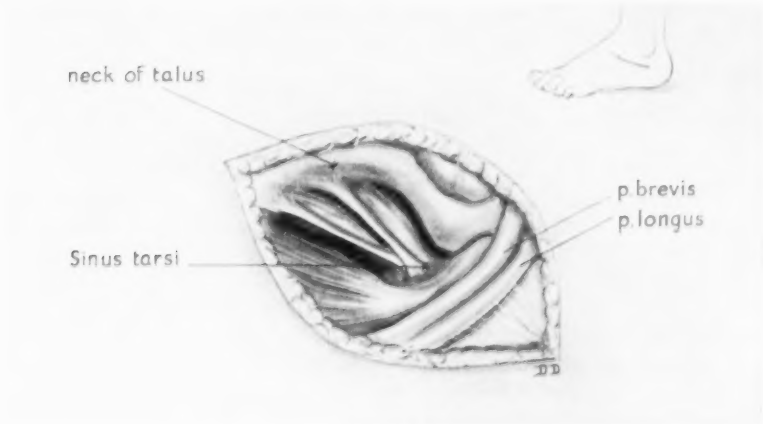

FIG. 6

Case 6—The sinus tarsi and related structures. The stem of the inferior extensor retinaculum or "ligamentum frondiforme" of French anatomists has been omitted for clarity. Note that the ligamentum cervicis (Wood Jones 1949) is represented as two ligaments of some strength.

ligament arose from the anterior aspect of the posterior articular facet on the calcaneum, and was a dense thickening of the anterior capsular ligament of the joint. (The normal foot has one strong ligament only in this situation, the ligamentum cervicis, described by Wood Jones in 1949). Its division allowed almost full inversion, the structures limiting full inversion then being the skin and soft tissues.

RESULTS OF TREATMENT

The results are shown in Table I. It will be seen that sixteen of the thirty feet had a full range of tarsal movement under anaesthesia, and of these four had severe tarsal anomalies. It is these rare cases which show good inversion under anaesthesia, in spite of tarsal anomalies, that are the most puzzling of the whole series.

Of the sixteen feet in which a full range of inversion could be produced under anaesthesia without any force, twelve showed powerful active inversion after the removal of the plaster at three months. The other four had reduced their degree of inversion while in a padded walking plaster, and after it was removed they could invert just beyond the neutral, but could not reach full inversion. Of these four, one had a vertical talus, one had an accessory tarsal navicular, one showed marked porosis, and the fourth showed no radiographic abnormality.

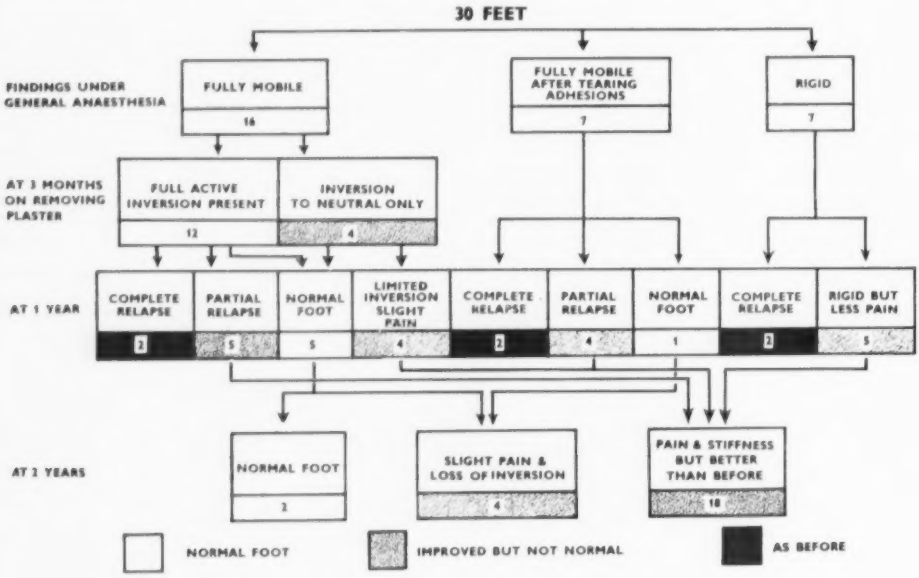

FIG. 7

Diagram showing the behaviour of thirty feet during the two years of observation.

Results one year after beginning of treatment—The results at one year showed that of these sixteen feet six were still symptom-free and possessed a full range of active inversion. The four mentioned above in which full passive inversion was present after removal of the plaster, but limited active inversion, remained the same at one year. They had inversion just beyond neutral, but the natural lie of the foot was everted, and there was a return of slight pain. The remaining six relapsed to some degree; two completely, and four having evertor spasm, loss of inversion, and slight pain, although considerably less than when they first attended.

To summarise this: of sixteen feet freely mobile under general anaesthetic, six were normal; eight were slightly better than before manipulation, although they had some pain and some valgus; and two had reverted to the fully established painful deformity. Of the two with complete relapse, one had a calcaneo-navicular synchondrosis and the other a complete bar.

Of the seven feet in which full inversion was obtained only after tearing adhesions, one was normal a year later, four lacked full inversion but caused no pain, and in two pain and

valgus had returned as before. Thus five out of seven were still better than they were before treatment. Of these five, one had no bony anomaly, three had minor anomalies, and one had a complete bar. The two feet that had relapsed completely both had calcaneo-navicular synchondroses.

Taking these together as one group in which full inversion was possible under anaesthesia, we find at one year that of twenty-three feet seven were normal, and a total of nineteen were improved on their condition before manipulation.

Of the seven feet that remained fixed in eversion after the manipulation, two were slightly better at one year, and five were unchanged by the manipulation. Of these seven, four had talo-calcaneal bars, one had a tongue-like prolongation of the front of the calcaneum, and two had severe midtarsal lipping. Two of the seven received subtalar and midtarsal fusion at two years.

Results two years after beginning of treatment—Of the twenty-three feet in which full inversion was possible under anaesthesia, we have seen that seven were normal feet at one year. Three of these remained normal at two years. Of the remaining four patients one developed a hysterical inversion deformity and the other three lost some of their inversion range and complained of slight pain after exertion. The seventeen feet that were improved but not normal at one year deteriorated during the second year, and eight returned more or less to the same state as when first seen. Four feet required subtalar and midtarsal arthrodesis. Of the original total of thirty feet, two were normal, sixteen were improved in varying degree, eight were the same, and four required operation. An analysis of these results is shown in diagrammatic form in Figure 7.

Comment—The feet that were improved by the treatment belong to the group which showed mobility under anaesthesia, and cures were seen only in those feet with normal tarsal architecture.

Crushing of the nerves to peroneus brevis gave temporary relief of signs and symptoms, but often the evertor spasm occurred in other muscles, and with it a return of symptoms.

Observation of these cases for two years did not reveal the evolution of rheumatoid arthritis in any one. Three patients had a sedimentation rate of over 15 millimetres in one hour when first seen; one of these, and one other, showed radiographic osteoporosis, but none developed any further changes indicating a generalised disturbance.

SUMMARY AND CONCLUSIONS

1. This paper reports the investigation and the results of a line of treatment in thirty feet showing the peroneal spastic flat foot deformity. The questions that have aroused controversy are discussed, the evidence for previous opinions is examined, and some phenomena in relation to this condition are described.

2. It is suggested that previous opinions on this condition have been misleading, and have in many cases been made after incomplete investigation of too few cases.

3. Peroneal spastic flat foot can occur without a developmental tarsal anomaly.

4. The presence of a tarsal anomaly does not necessarily mean that the foot is incorrigibly stiff, and some of these feet show a full range of movement under anaesthesia.

5. There is no evidence from this series of cases to suggest that organic nervous disease or psychiatric disturbances played a significant part in the production of the deformity.

6. There is no evidence to suggest that the deformity is a manifestation of generalised rheumatoid arthritis.

7. This investigation does not reveal the cause of the deformity when the tarsal skeleton is normal, nor does it help to explain the reason for the onset of symptoms in a developmentally abnormal foot.

8. It is suggested that a tarsal anomaly makes the foot more likely, under average stress, to break down in this way, and that this deformity is also assumed by architecturally normal

feet under heavy stress. In view of the frequency of minor tarsal anomalies among this series of thirty feet, it seems likely that all feet presenting the deformity of peroneal spastic flatness are to some degree structurally abnormal, although the exact site of the abnormality may escape us.

My thanks are due to Mr D. Ll. Griffiths for help with this paper; to Sir Harry Platt and Mr John Charnley for permission to study their cases; and to the Department of Medical Illustration, Manchester Royal Infirmary, for their photographic work.

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THE SURGICAL TREATMENT OF TARSO-METATARSAL FRACTURE-DISLOCATIONS

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Fracture-dislocation of the tarso-metatarsal joints—often called Lisfranc's fracture-dislocation—is probably commoner than is generally supposed. In little over a year and a half I have encountered thirteen fresh cases, five of which had not been recognised on the first examination. The greatest incidence is among farm labourers and the mounted forces (Roca 1945). The injury usually results from a fall; the mechanism is a forced inversion or supination of the foot, a rotary movement that finds the weak point in the tarso-metatarsal joint, dislocating the metatarsals partly or completely from the cuneiforms or from the cuboid. The anatomical extent of the injury is variable; but in most cases the damage is greatest at the level of the first interosseous space, as though the violence were endeavouring to separate the first metatarsal from the remaining four.

There has been considerable divergence of opinion among surgeons on the best method of treating these injuries. In Argentina, Wybert and Perez Rovira (1944) favoured open reduction, and Comolli and Esteban (1947) reported successful results in three patients treated by internal fixation with metal plates. Gissane (1951) pointed out that Lisfranc's fracture-dislocation, caused nearly always by a rotary strain on the forefoot, is always associated with some degree of arterial damage. The only other mention we have found of this complication is in a paper by Ferreyra and Arredondo (1940), who reported injury to the dorsalis pedis artery. In most descriptions (Quenu and Kuss 1909) attention is drawn to the almost constant separation between the first and second metatarsals with the tearing of the soft tissues that is to be expected. At this point the communication between the dorsalis pedis artery and the arch is torn. Gissane considered that the arterial injury does not endanger the life of the foot unless the posterior tibial or the lateral plantar artery should also be damaged. He mentioned three cases of severe arterial damage which culminated in amputation. Even in cases with only slight displacement he favoured open reduction, believing that a better functional foot was ensured by repair of the soft tissues and accurate reposition of the bones.

After returning from England in 1951 I had the opportunity to treat a patient with this injury according to the new ideas I had formed—that is, by open reduction but with internal fixation by temporary percutaneous wire transfixion, thus avoiding the use of screws, plates or non-absorbable suture material. Since then I have treated a further twelve patients with similar injuries, though not all with severe displacement. Of the total of thirteen cases three were treated by closed reduction, two by physiotherapy alone, and eight by operative reduction.

TECHNIQUE OF OPERATION

With the limb exsanguinated by a tourniquet a dorsal incision is made in the first interosseous space. Blood clot is cleared out and the termination of the dorsalis pedis artery is inspected. In nearly all the cases there was not found the communication between the dorsalis pedis artery and the plantar arch. The haematoma varied considerably from one case to another. In no instance did we find the artery severed and bleeding. After clearance of bone fragments, bits of cartilage or soft tissue from the first interosseous space, the jagged ends of the tarsal bones and the metatarsals are reduced. Usually by levering the second

* Director, Professor José Valls.

metatarsal and supinating the foot a good reduction can be obtained and maintained. In some cases a second incision is necessary to reduce the third or fourth metatarsal.

Fixation is secured by transfixion with wire pins, inserted with a pneumatic or electric drill; the number of wires needed varies from one to four. The wires are included in the plaster and retained for two to four weeks. After they have been withdrawn the patient is encouraged to walk with a below-knee plaster.

RESULTS

The results of operative reduction were good in all cases. There were no complications and the wires produced no ill-effect. In no instance did redisplacement occur. There was no

FIG. 1

FIG. 2

Case 2. Figure 1—Before reduction. Figure 2—After operative reduction and fixation by wires.

vascular disturbance except in one case in which a certain amount of infiltration remained, with slight subcutaneous oedema. In no case was arthrodesis required, but the erasing of the tarso-metatarsal line was evident in the radiographs after a few months.

CASE REPORTS

Case 1—A labourer aged twenty sustained a Lisfranc's fracture-dislocation when a horse stamped on his left foot. During operative reduction it was necessary to excise a small piece of the second

metatarsal before accurate replacement could be obtained. One transfixion wire was used to prevent redisplacement. Progress was good and he was discharged fit for work three and a half months after the injury.

Case 2—A stevedore aged fifty-five suffered injuries, including a Lisfranc's fracture-dislocation when he fell twenty feet (Fig. 1). Closed reduction was attempted but was only partly successful. Open reduction was undertaken two weeks after the injury. It was necessary to expose both the first and fourth interosseous space, and a piece of the second metatarsal that was impeding reduction had to be excised. The position was maintained by four transfixion wires incorporated in the plaster (Fig. 2). The foot remained slightly swollen but the result was good.

Case 3—A clerk aged forty-four fell six feet, twisting his right foot. There was severe displacement (Fig. 3). Immediate closed reduction was attempted without success. Open reduction was carried out and the bones were secured by two transfixion wires (Fig. 4). The result was satisfactory.

Case 4—A woman fell down some steps, twisting the left foot and causing a Lisfranc's fracture-dislocation. Several attempts at closed reduction were unsuccessful. A good result followed operative reduction by the method described.

FIG. 3

FIG. 4

Case 3. Figure 3—Before reduction. Figure 4—After operative reduction, showing the temporary transfixion wires in position.

Case 5—A labourer aged forty had his right foot crushed by a cart. Open reduction was performed and the position was held by a transfixion pin through the second metatarsal and first cuneiform which was also fractured. The result was good.

Case 6—A woman aged thirty-five was injured when a log of wood fell across her left foot. There was marked deformity (Fig. 5). After open reduction the position was maintained by two transfixion wires incorporated in the plaster for two months (Fig. 6). Progress was satisfactory.

Case 7—A man aged twenty-eight slipped from a bus, twisting his right foot. There was minor displacement of the first and second metatarsals. They were levered back into position through an incision exposing the interosseous space, and reduction was maintained by one transfixion wire and plaster. A good result was obtained.

Case 8—A man aged thirty-eight sustained a compound fracture-dislocation of the first tarso-metatarsal joint when a sheet of iron fell upon his left foot (Fig. 7). There was an extensive laceration

at the medial border of the foot and the medial plantar artery was torn. At immediate operation all damaged soft tissue was excised and the dislocation was reduced. The position was held by a transfixion wire, the wound being only partly closed (Fig. 8). Four weeks later the wire was withdrawn and the wound closed by skin-grafting. A perfect anatomical and functional result was obtained.

FIG. 5

FIG. 6

Case 6. Figure 5—Before reduction. Figure 6—After operative reduction.

FIG. 7

FIG. 8

Case 8. Figure 7—Before reduction; marked displacement of base of first metatarsal. Figure 8—After operative reduction, with transfixion wire in position.

COMMENT

The possibility of vascular lesions should always be borne in mind, but the risk is probably not serious when the lateral plantar artery is intact. To reduce the risk of vascular impairment reduction should be carried out as soon as possible.

The method that I have described ensures excellent fixation without the use of any internal metal that might require removal later.

SUMMARY

1. In the treatment of tarso-metatarsal fracture-dislocations open reduction is advocated whenever closed reduction is found impossible.

2. A technique of operation is described whereby, after reduction, temporary transfixion wires are used to prevent redisplacement.

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LUMBO-SACRAL ARTHRODESIS AFTER LAMINECTOMY*

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The necessity for arthrodesis of the lumbo-sacral spine after laminectomy has been performed arises mainly in the treatment of spondylolisthesis and some lesions of the intervertebral discs. In most cases of spondylolisthesis the lamina is loose and unattached to its body, so it can play no useful part in the fusion operation. Apart from this, it should in all cases be removed to allow a thorough decompression of the cord and nerve roots. In the operation for exploration of a disc it is impossible to get adequate exposure of the lower two disc spaces unless the spinous process and at least one half of the lamina of the fifth lumbar vertebra are removed. Sometimes, especially in the L.4–5 segment, it is necessary also to remove the medial facet of the posterior intervertebral joint, and this is not infrequently removed inadvertently. I do not believe that arthrodesis is necessary in the routine treatment of all cases of disc prolapse, but in the cases in which it is considered necessary there will usually be too little of the neural arch left for the performance of a satisfactory posterior arthrodesis. The commonest indication for fusion is the so-called scarred disc, in which severe backache is associated with some sciatic radiation. Although a prolapsed nucleus will not usually be found in these cases it is most important that a thorough exploration of both the affected and adjacent discs should be made to exclude its presence. For the same reason, although disc lesions probably play an insignificant part in the common low back pain syndrome, until the etiology of this condition is better understood it is unwise to perform a posterior arthrodesis without first exploring the disc spaces. In both cases the exploration inevitably removes the basis of a sound posterior fusion.

In the past this problem has usually been tackled by using a long graft to bridge the laminectomised vertebra. An attempt is thus made to fuse two intervals, most commonly the fourth lumbar to sacrum. The choice lies between an onlay cortical graft as used by Albee (1911) or one of its many modifications, perhaps a graft fixed to spinous processes by bolts and plates as described by Wilson and Straub (1947), or the H-graft impacted between spinous processes as used by Bosworth (1942). All are open to the same criticisms: the gap to be bridged is too large; the lever-like action of a long graft greatly exaggerates the slight movements which are so hard to eliminate in this region; and the sacral spinous process is so often absent or ill-developed that adequate fixation of the sacral end is impossible. All published results show a greatly increased rate of failed fusion when more than one interval is spanned. Cleveland, Bosworth and Thompson (1948), in a review of 594 cases of grafts of various kinds, quoted an increase from 3·5 per cent for the lumbo-sacral interval only to 17·3 per cent for the fourth lumbar to sacral interval, and a figure as high as 35 per cent for spondylolisthesis cases. For reasons to be mentioned later, I believe that even these results may represent a too optimistic view of this problem. My own experience of these types of graft is small, but none the less unfortunate. Excluding fusions done for fracture or tuberculosis, I have been able to study the late result in eight cases, of which at least four are certain failures.

Many writers have mentioned the need for improved methods of arthrodesing this region of the spine, especially in cases of spondylolisthesis, and during the past six years I have devoted much time and thought to attempts, mostly unsuccessful, at solving this problem. A bone graft inserted between the vertebral bodies through the same posterior approach and at the same time as the exploratory operation seemed to offer much promise.

* Part II of an essay adjudged *proxime accessit* in the competition for the Robert Jones prize 1953. Part I appeared in the February 1955 issue of the Journal.

A few reports of such a procedure have appeared in the literature (Cloward 1953, Jaslow 1946, and James and Nisbet 1953) but so far as I am aware none of these writers has studied the late results or attempted to assess the incidence of pseudarthrosis. This method seemed to me to be the perfect bone-grafting procedure, but a study of the late results in an extensive series, described in detail later, has convinced me that these grafts seldom become incorporated.

Having accepted, albeit reluctantly, the complete failure of the intercorporal method, I turned my attention to the lateral elements of the vertebra which remain after laminectomy—namely the pedicles and transverse processes. An interpedicular (or alar-pedicular) fusion, although it produced a few good results, was considered unsatisfactory for technical reasons and was soon abandoned in favour of the more certain intertransverse (or alar-transverse) arthrodesis.

Before relating my experiences with these various methods of grafting, I wish to make some comments on two problems that are common to all methods: firstly, the difficulty of determining whether fusion has occurred or not; and secondly, the difficulty of adequately immobilising the lumbo-sacral region of the spine.

ESTIMATION OF FUSION

Many surgeons have assessed the value of an arthrodesis by the subjective test of relief from symptoms. Such an assessment is so obviously unreliable that it needs no further comment. An assessment can be based on the direct radiological evidence of incorporation of the grafts. This method is seldom helpful because most spinal grafts are obscured by other parts of the vertebra and cannot be displayed clearly enough to show definite incorporation. The usual test therefore is by mobility films. The technique consists of taking lateral projections of the spine in flexion and extension, and antero-posterior films in right and left lateral flexion. Absence of movement in the grafted segment is accepted as evidence of bony fusion.

In attempting an end-result study by this method, however, I soon found myself in grave difficulties. However carefully the position of the patient is controlled it is virtually impossible to maintain a constant relationship of the x-ray tube to the patient, or of the patient to the film. The result is that exactly comparable films cannot be produced and, even if solid fusion is present, the bony outlines can rarely be accurately superimposed. In many cases, even after repeated investigations, I found it impossible to decide whether these slight differences were due to this factor or to lack of complete immobility which, of course, would indicate a failed arthrodesis. Bosworth (1948) mentioned that the antero-posterior radiographs may not superimpose accurately because of what he called the " stereoscopic effect " of slight shifts, but he stated that all outlines should remain parallel. This is an over-simplification of the problem, and ignores the fact that any shift of the patient, and especially slight rotation, may bring quite different contours into the outlines on the radiograph. These need not necessarily be parallel to the earlier ones. Armstrong (1952) also noted the unreliability of this method.

A statistical investigation was made still more difficult by the occurrence of a few cases in which, from obesity or a marked degree of spondylolisthesis, it was impossible to obtain radiographs good enough for comparative study.

The interpretation of mobility films is rendered difficult by a still more important factor. After any extensive operation on the lumbo-sacral spine involving partial laminectomy there is often dense fibrosis in the region of the excised lamina and ligamentum flavum, and also within the intervertebral space itself if the disc has been resected. Anyone who has been unfortunate enough to have to re-explore such cases is only too well aware of this fact. This fibrosis greatly reduces the mobility in this segment, and often leads to a firm fibrous ankylosis, even when no bone graft has been inserted. In an investigation of sixty patients subjected to simple resection of a disc without arthrodesis, I found that mobility of the affected segment

was absent or almost absent in 40 per cent. With the more extensive interference necessary for a grafting procedure, one might expect this figure to be increased considerably.

In assessing the results of lumbo-sacral arthrodesis by this method, therefore, an attempt is being made to estimate mobility of joints in which movement is likely to be slight or absent, even if the arthrodesis is unsuccessful. The investigator has to distinguish such cases from those of true bony fusion which show apparent slight mobility from changes of position during radiography. From my own experiences while investigating over a hundred cases by this method, I believe it to be subject to grave personal error which could seriously upset one's judgement of the value of any particular method of arthrodesis. Such an investigation of my earlier cases of intercorporal bone grafting deceived me so completely that I believed fusion was occurring in nearly every case. Thus encouraged, I operated upon a large number of patients, and it was only after a much later follow-up that I realised that the results were very different from what I expected.

Many surgeons reporting cases of lumbo-sacral arthrodesis have assessed their results by this method. Most have claimed a high proportion of successful fusions. I think it significant that, apart from the authors mentioned above, I have seen no reference to this difficulty of interpreting mobility films, although I cannot believe that any of these investigators have failed to experience it. Until more is known of the criteria accepted for bony fusion I believe that many of the previously published figures should be accepted with the greatest reserve.

IMMOBILISATION OF THE LUMBO-SACRAL REGION

Immobilisation of the lumbo-sacral region has always presented a difficult problem, and it is doubtful whether any of the usual methods is entirely satisfactory. A well fitting plaster jacket will limit movement of the lumbo-sacral joint, but it will certainly not prevent movement altogether while hip movements and the associated rotation of the pelvis are left uncontrolled. Both spine and hip movements can be controlled either by a plaster bed or by a combination of a plaster jacket and double short hip spica. A patient immobilised by the latter method presents a formidable nursing problem, and runs the risk of serious chest or urinary tract complications. I have used it only on rare occasions.

Theoretically the plaster bed, which controls spine, pelvis and hip movements, offers the most satisfactory method of immobilisation. I have used it routinely in cases such as those of spondylolisthesis in which arthrodesis was considered an essential part of the operation. In practice, however, I doubt whether the immobilisation is altogether successful, for these patients almost invariably flex their hips, prop themselves up with pillows, or even turn on to their sides to speak to their neighbours!

After most of my operations for disc lesions in which arthrodesis was considered desirable but not absolutely essential, I have compromised with a combination of plaster jacket and single short hip spica. This is applied a few days after the operation and the patient is allowed up in the plaster. Most patients soon learn to walk, sit down and use the toilet, and can be discharged home or to a convalescent home. The plaster is retained for fourteen to sixteen weeks, and then replaced by a plaster corset or Jordan's brace. Movements of the uncontrolled hip probably cause slight rotation movements of the pelvis within the plaster, with the possibility of slight movement at the lumbo-sacral joint. I have come to the conclusion, however, that in practice this method ensures better immobilisation than a plaster bed.

In some cases I have tried internal fixation with a Wilson plate bolted to the spinous processes. It is often not practicable on account of deficiency of the sacral spine. In many cases firm fixation has been demonstrated on the operating table by flexing the spine before closing the wound. But in every case the bolt through the sacral spine has loosened, often within a few days after the operation. In my opinion plates and bolts alone cannot be relied upon to give even temporary fixation.

Some surgeons, especially in America, have discarded plaster fixation altogether, and

allowed the patient up in a lumbo-sacral brace. This does not immobilise the spine, and at best can only partly restrict movements at the lumbo-sacral joint. Adequate immobilisation is still considered necessary to effect arthrodesis in almost any other joint in the body, and until more satisfactory end-results can be demonstrated it seems foolish to discard this important aid to fusion in this region.

It is possible that the difficulty of securing fusion of the lumbo-sacral joint is largely explained by the impossibility of providing adequate immobilisation, particularly when long grafts are used. These often appear to fuse at one end but develop a pseudarthrosis at the other end, where any slight movements are magnified by the lever-like action of the long graft. To minimise this effect, when more than one segment has to be fused, and no matter what type of graft has been chosen, a series of short intersegmental grafts should always be used in preference to a single long graft. Firm impaction of the grafts between the two vertebrae to be fused can itself produce considerable fixation; and while the available methods of immobilisation, either external or internal, remain unsatisfactory this is probably the best safeguard against failure.

THE INTERCORPORAL BONE GRAFT

Cancellous chip grafts—In my initial attempts at producing intercorporal fusion the excavated disc space was packed with bone chips. The method posed many problems. It is

FIG. 1

Case 1—Spondylolisthesis. Radiograph four years after packing cancellous chips between the vertebral bodies. The only case in which such grafts consolidated.

FIG. 2

Case 2—Radiograph four and a half years after intercorporal cancellous chip grafting. No consolidation of grafts, but fusion by anterior bridge.

obviously important to bare as wide an area as possible of the contiguous surfaces of the vertebral bodies by removal of the cartilaginous plates. As the cartilage is usually firmly adherent to the bone it is difficult to do this with a spoon, and the dome-shaped surfaces of the vertebrae make access with a gouge equally difficult. After a thorough curettage of the disc space a large quantity of bone chips is required to fill it—far more than are provided

by the excised spinous process and lamina. Extra bone has therefore to be obtained from the ilium, with the disadvantage of a new incision and considerable waste of time. To overcome the danger of retropulsion of the chips, the gap in the posterior annulus must be closed with a piece of bone impacted under its edges, and the patient must be nursed on his face for two to three weeks.

On account of these difficulties and the lack of radiographic evidence of consolidation of the grafts, the method was soon abandoned in favour of the solid graft described later. A much later follow-up of these cases showed that the results were not satisfactory, but some interesting observations are thought to be worth reporting and may be of interest to others who have tried this method.

Of five patients (four with disc lesions and one with spondylolisthesis) only the one with spondylolisthesis showed evidence of consolidation across the disc space (Fig. 1). Mobility

FIG. 3

FIG. 4

Case 3—Scarred lumbo-sacral disc. Intercorporal spinous process graft. Figure 3—Early post-operative radiograph. Figure 4—Two years after operation: pseudarthrosis at upper end of graft.

films confirmed that this segment was stable. In none of the remaining four cases, nor of several others in whom chips were used in conjunction with a solid graft, was there evidence of consolidation of the chip grafts. In one case radiographs taken four and a half years after operation still show no evidence of consolidation, although the chips are still visible in the disc space. Mobility films suggest stability, but I believe this is due to fibrous ankylosis and not to bony fusion; this impression is supported by one of the other cases in which the radiograph of the disc space is exactly similar, but in which there is definite movement in the mobility films. What peculiar circumstances resulted in the one successful fusion remains a mystery.

In one other case fusion occurred through a firm bony bridge in front of the vertebrae (Fig. 2). This closely resembles the anterior fusion seen after some cases of fracture of the vertebral bodies. A similar anterior or antero-lateral bony bridge (sometimes visible only in

oblique films) has been seen in one case with an intercorporal solid graft, one with an interpedicular graft, and in one case after simple disc resection. The factors in the operative procedure responsible for this desirable end-result remain obscure. It is possible that it is caused by haemorrhage under the anterior longitudinal ligament after deep curettage of the disc, but the rarity of its occurrence makes this unlikely. Just as it is the ideal end-result of a fractured vertebra, it would probably be the ideal end-result of disc resection also, if only it could be produced to order.

Solid cortical grafts—Since the chip grafts failed to consolidate, a technique using a solid graft was developed. After curettage of the disc space, slots about half an inch long were cut in the opposing surfaces of the vertebral bodies on each side of the disc space. The osteotome was driven into the body of the vertebra to a depth of about three-quarters of an inch. A graft cut to the appropriate size was then inserted into these slots and across the

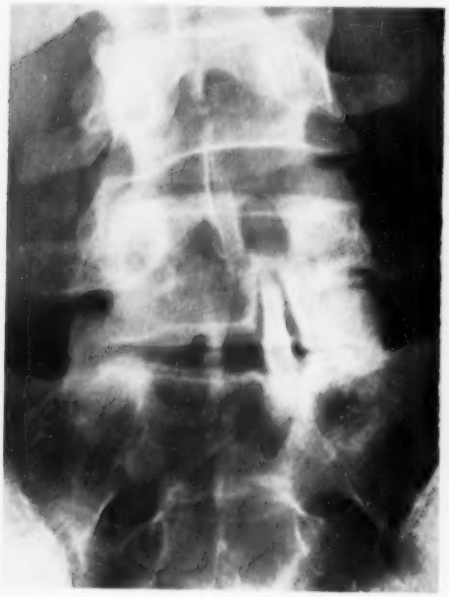

FIG. 5

Case 4—Intercorporal spinous process graft two and a half years after operation. There is a pseudarthrosis at each end of the graft.

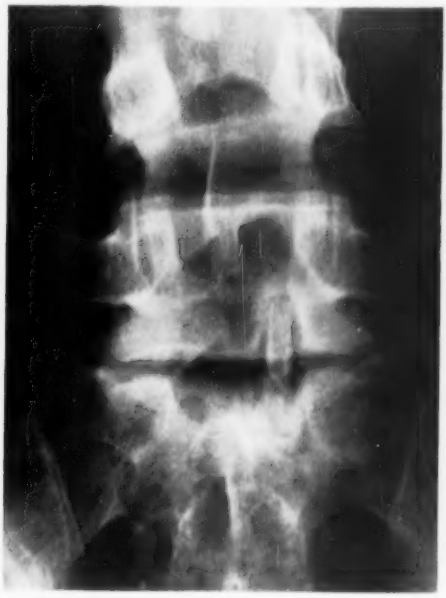

FIG. 6

Case 5—Lumbo-sacral intercorporal graft eight months after operation. There is a pseudarthrosis in the middle of the graft.

disc space (Figs. 3 to 8). At first a spinous process cleaned and freshened was used for the graft, but in some of the later cases a tibial graft was used instead (Fig. 7). The operation was performed with the spine flexed, and on extending the spine the graft was firmly impacted within its bed.

After I had become familiar with this technique it became an easy and attractive procedure, adding no more than a few minutes to the operating time for disc resection. It seemed an ideal grafting procedure, because the graft was in close contact with a wide area of the host bone, and was not only firmly fixed but actually under compression when the spine was extended. Estimation of fusion by the mobility method produced films which could be completely or almost completely superimposed and were interpreted as showing bony fusion of the grafted segments. Although I do not believe that arthrodesis is essential for all cases of disc prolapse it would be desirable if it could be effected as simply and quickly

as by this method. The method was therefore adopted routinely for all cases of disc resection and spondylolisthesis operated upon in 1949–50. It was used in seventy cases, fifty-eight of disc resection and twelve of spondylolisthesis. The joint grafted was the lumbo-sacral in thirty-eight, lumbar 4–5 in nineteen, and both joints in thirteen cases. In the earlier cases chips from the excised lamina were packed around the solid graft, but as no visible consolidation occurred in these, this addition was discontinued. In twenty-six, twin grafts were used, one inserted from each side. In nine of the later cases tibial grafts were used instead of the spinous processes.

Results—The difficulty of estimating fusion in the lumbo-sacral region by mobility films has already been stressed. In most cases investigated the films showed either no movement or a very slight shift which was thought to be due to changes in position during radiography. A detailed radiological investigation of the grafted area was therefore undertaken in the hope

FIG. 7

Case 6—Intercorporal tibial grafts for spondylolisthesis a year after operation. Pseudarthrosis at upper end of right graft and lower end of left graft.

FIG. 8

Case 7—Intercorporal tibial graft for spondylolisthesis. Radiograph one and a half years after operation shows the graft partly absorbed.

of finding direct evidence of incorporation of the grafts into the host bone. Such an investigation is difficult, for the embedded parts of the grafts are often obscured by superimposed shadows of other parts of the vertebra. Instead of providing evidence of bony fusion, the follow-up radiographs gave direct evidence of failure of incorporation of the grafts. With the possible exception of one single graft, the study has failed to produce evidence of incorporation of any of these grafts in two to four years. Whether use was made of single or twin grafts, tibia or spinous process, with or without chips, the results were the same.

In many cases a definite pseudarthrosis was shown at one end of the graft, where there was well defined sclerosis around the margins of the bed and often a gap between this sclerosed margin and the inert graft lying within it (Figs. 4, 5, 7, 8). This was much the commonest finding. In a few cases there was a pseudarthrosis within the graft itself where it bridged the disc space (Fig. 6). In others there was partial absorption of the graft (Fig. 8). In none was

there evidence of a build-up in strength of the graft, or of buttressing with new bone, such as is seen so commonly in the comparable ischio-femoral graft of the hip joint or in the intertransverse spinal graft to be described later. If these grafts had really become incorporated such changes would almost certainly have occurred.

These rather startling conclusions led me to review and in most cases repeat the radiological investigation of mobility in these grafted segments. Sixty-six patients were reinvestigated and the results were as follows: no movement, seventeen (26 per cent); doubtful or slight movement, thirty-four (51 per cent); definite movement, fifteen (23 per cent). There was no difference in the appearance of the grafts in these three groups, and in many immobile joints the characteristic appearances which I am now convinced indicate failure of bony fusion were evident. In relation to other published figures, it may be of some significance that had the findings in the first two groups been accepted as evidence of bony fusion (I was originally inclined to do this) a figure of 77·2 per cent of successful arthrodeses might have been claimed. This figure compares closely with many published results.

I now feel certain that intercorporal bone grafting, although it appears to aid the formation of a firm fibrous ankylosis, is ineffective as a method of producing bony arthrodesis. It is nevertheless worth recording that in none of these cases was there any complication attributable to the graft. There were no cases of sepsis; and, as evidenced by the relief of symptoms in many cases of spondylolisthesis, it seems that fibrous ankylosis is almost as effective as bony arthrodesis.

Discussion—What is the reason for this total failure of a method which theoretically approaches the ideal? The avascularity of the gap to be bridged across the disc space suggests a possible cause. In this case, however, one would expect the pseudarthrosis to develop in the middle of the graft. But on the contrary, the pseudarthrosis is between one end of the graft and the host bone. It might be due to the inefficient immobilisation which is inevitable in this region. This factor, however, is not peculiar to the intercorporal graft and cannot explain the discrepancy in the pseudarthrosis rates between this method and the more conventional types of grafting. I believe the answer lies in some intrinsic factor peculiar to the bone of the vertebral bodies. This would explain not only the failure of incorporation of these grafts but also the absence of consolidation of vertebral bodies after compression fractures.

LATERAL FUSION

Failure of the intercorporal method led me to consider the possibilities of using the lateral elements of the vertebrae which remain after laminectomy. In spondylolisthesis, the inferior facets are attached to the loose lamina and so are of no use. After excision of a disc the facets will usually be left intact on at least one side, but there is no really satisfactory method of using them in a grafting operation. The difficulty of removing the articular cartilage from between the facets has been referred to by many surgeons, and even if this is done satisfactorily, there is a considerable gap left which has to be filled in with free grafts. Grafts laid across the facets or along their lateral surfaces cannot be adequately secured and act purely as onlay grafts. I feel certain that it is impossible to perform a satisfactory arthrodesis operation using these elements alone.

There are left therefore only the pedicles and transverse processes. A technique of fixing grafts between the pedicles or between pedicle and ala of sacrum was developed. Adequate fixation is difficult to secure and this method was soon discarded in favour of the more certain intertransverse or ala-transverse method to be described. A few satisfactory fusions were obtained by this method, however, and it is possible that it could be modified into a more satisfactory procedure. In view of this I think the technique and results of the few cases so dealt with are worth reporting.

Bosworth (1948) used the transverse processes in a grafting procedure for cases of pseudarthrosis after attempted arthrodesis by other methods. The technique described below

has produced some very satisfactory results and offers great promise as a solution to the problem of arthrodesis after laminectomy.

INTERPEDICULAR GRAFTS

Technique—The pedicles are nibbled down to form flat surfaces just clear of the emerging nerve roots as they curve round their inferior surfaces. A tibial graft drilled at each end is laid across the pedicles and the drill is passed through the pedicles and into the vertebral bodies (Fig. 9). Into these drill holes bone pegs cut to the shape of a tent peg are driven. Unfortunately there is no means of compressing the graft against the pedicular surface and it is often difficult to keep it in close contact with its bed. For the lumbo-sacral segment, the lower end is either driven into a hole cut in the ala with a curved gouge or punched into

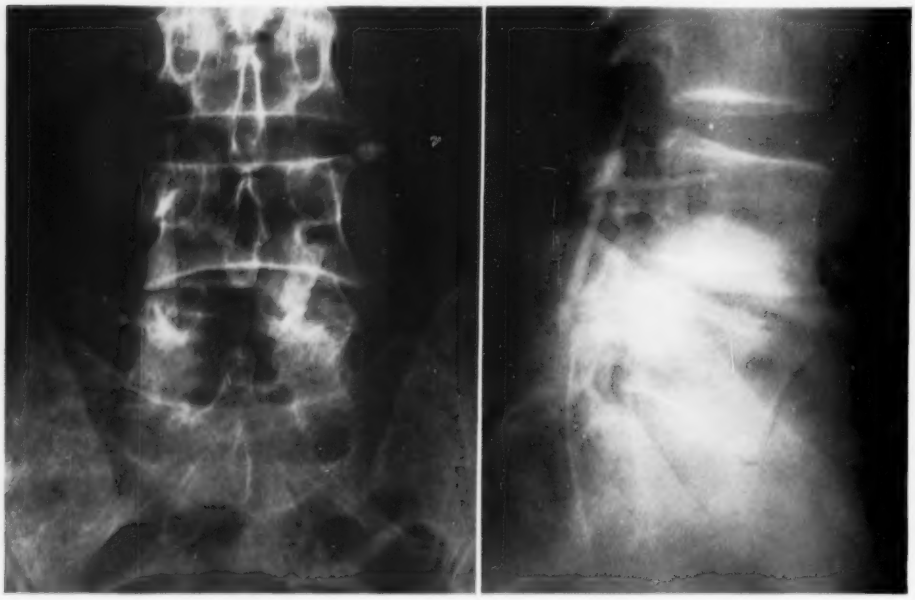

FIG. 9

Case 8—Interpedicular grafts bridging the L4–5 joint. Note bone pegs holding the grafts, one extending into the body of L4.

a slot cut in the upper border of the ala. The latter method is the more satisfactory as it is difficult to cut a hole in exactly the right direction.

Results—During 1951 eight patients (five with disc lesions and three with spondylolisthesis) were operated upon by this method. In five the joint concerned is stable and there is definite evidence of incorporation of the grafts (Fig. 10). The three others, all in the lumbo-sacral interval, have failed.

INTERTRANSVERSE GRAFTS

By continuing the dissection of the erector spinae laterally from the pedicles it is possible to expose the transverse processes and alae of the sacrum. This is easier when the facets have been removed but if these are intact it can be performed quite satisfactorily without disturbing them. A groove is cut in the upper or lower border of the transverse process with a sharp gouge or Citelli's forceps. Great care must be taken over this part of the operation, for the transverse process is easily fractured, and in the event of fracture firm impaction of the graft is impossible. In the ala of the sacrum parallel cuts are first made

in its postero-superior border with an osteotome, and a gouge is then driven across the ends of these cuts and the intervening bone levered out of the slot so made. For the lumbar 4–5 joint a tibial graft is cut with V-shaped ends; it is inserted obliquely between the transverse processes and then rotated into position so as to cause slight distraction of the processes and become firmly impacted between them. For the lumbo-sacral joint the graft is cut V-shaped at its upper end and straight but slightly obliquely at its lower end. One arm of the V is inserted in front of the transverse process and the lower end is punched into the slot in the sacrum. The slight wedging of the lower end ensures firm impaction as the graft is punched home. Bilateral grafts are best because they afford a considerable degree of internal fixation. If one side only is grafted the patient must be so arranged that there is a slight convex curve of the spine on this side so that firm impaction will occur when the spine is straightened.

FIG. 10
Case 8—Later oblique radiograph showing full consolidation of the graft on the right.

The grafts must be placed as far laterally as possible to avoid their contact with the emerging nerve roots, and also to gain the maximum mechanical stability.

If two spaces have to be arthrodesed, two separate intersegmental grafts should be used to avoid the lever-like action of a long-graft previously mentioned.

In some cases bone chips were packed around the grafts but I believe this to be unnecessary if the grafts are firmly impacted. On two occasions I have dispensed with a solid graft and turned the transverse process itself into a groove cut in the ala. Although theoretically attractive, in practice it is difficult to get satisfactory contact and the process will almost certainly fracture and possibly become displaced. Although fusion seems to be occurring in both these cases it is not a procedure that I would recommend.

Results—I first performed this operation in April 1951, and it has not so far been possible to undertake a late follow-up study on an extensive series. It may be said, however, that the method has given some very beautiful results, in which certain and solid incorporation of the grafts can be seen in the radiographs, and in which there is no need to rely on the doubtful evidence of mobility films (Figs. 11 to 17). In the light of experience many modifications have been made in the technical details of the operation, and I believe that most of the failures can be attributed to obvious technical errors.

FIG. 11

Case 9—Lumbo-sacral spondylolisthesis treated by bilateral tibial ala-transverse grafts. Six months after operation the grafts are incorporated and buttressed by new bone.

FIG. 12

Case 10—Lumbar 4–5 spondylolisthesis and lumbo-sacral spondylolysis. Separate intertransverse grafts L 4–5 and L 5–ala. Six months after operation grafts are well incorporated.

FIG. 13

Case 11—Lumbar 4–5 spondylolisthesis, eight months after bilateral intertransverse fusion with tibial grafts. Note massive buttressing at inner side of graft on left side.

FIG. 14

Case 12—Ala-transverse graft two years after operation. Oblique radiograph showing left graft fully incorporated at both ends.

FIG. 15

Case 13—Unilateral ala-transverse graft six months after operation. Oblique radiograph showing massive consolidation.

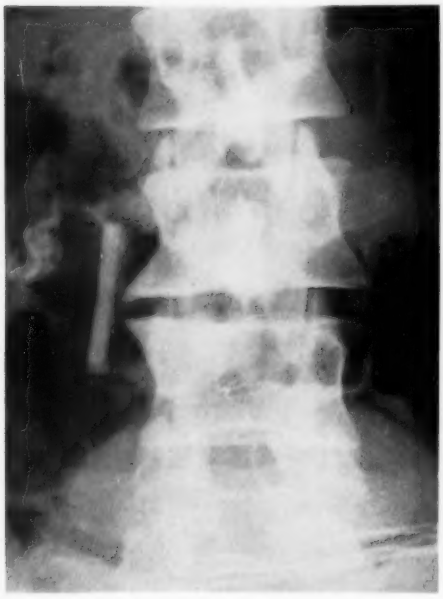

FIG. 16

FIG. 17

Case 14—Boiled tibial intertransverse graft bridging L 3–4 joint. Figure 16—Soon after operation. Note fractured lower transverse process. Figure 17—A year later. Full incorporation with buttressing at both ends of graft.

FIG. 18

Case 15.—Ala-transverse graft of boiled tibial bone. The graft has become disimpacted from the transverse process, probably because it was inserted on the concave side of a spinal curve as the patient lay on the table. The graft was later absorbed.

FIG. 19

FIG. 20

Case 16.—Ala-transverse graft of tibial bone. Figure 19.—Soon after operation. The transverse process has been fractured; the graft has moved upwards and is disimpacted from its bed in the sacrum. Figure 20.—A year and a half later. The graft is incorporated at its upper end but a pseudarthrosis persists at the lower end.

The commonest of these errors is failure to obtain firm impaction of the grafts. This may be caused by using too short a graft, by applying it to the concave side of a spinal curve so that it disimpacts on straightening the spine (Fig. 18), by failure to cut adequate grooves in the transverse process or ala, or by fracture of the transverse process (Figs. 19 and 20). Fracture does not necessarily prevent incorporation (Figs. 16 and 17) but I believe makes it less likely to occur. Placing of the grafts too medially, especially the lower ends (Figs. 21 and 22) reduces the mechanical stability of the segment and is another likely cause of failure. In a few cases boiled tibial grafts were used, and although many of these have incorporated satisfactorily (Figs. 16 and 17) they appear to be much less certain than autogenous bone (Fig. 23).

Up to the end of 1952 thirty patients (twenty with disc lesions and ten with spondylolisthesis) were treated by this method. One patient died from pulmonary embolism

FIG. 21

FIG. 22

Case 17—Lumbo-sacral spondylolisthesis. Bilateral ala-transverse grafts from tibia. Figure 21—Soon after operation. The grafts are implanted too medially in the sacrum and mechanical stability is impaired. Figure 22—A year later. The grafts have failed to become incorporated and are largely absorbed.

sixteen days after operation. In the remaining twenty-nine the results were as follows: certain fusion, seventeen (59 per cent); probable fusion, seven (24 per cent); failure, five (17 per cent). The cases listed as certain fusions show incontrovertible radiographic evidence of fusion (Figs. 11 to 17). In all of these the grafts are firmly incorporated at both ends and there is definite buttressing, often of massive dimensions, by new bone around the grafts. The cases listed as probable fusions all appear stable in mobility films, the embedded ends of the grafts appear incorporated, with no such evidence of pseudarthrosis as was seen in the intercorporal grafts, and the grafts appear healthy without any apparent absorption. They are listed as probable instead of certain fusions only because the conclusive evidence of buttressing by new bone cannot as yet be demonstrated.

In all five failures (four cases of disc lesion and one of spondylolisthesis) one or more of

the technical errors mentioned can be detected. In one case a boiled graft was used and the transverse process fractured; this graft absorbed completely. In another a boiled graft became disimpacted from the transverse process (Fig. 18) probably because it was inserted along the concave side of a spinal curve; this graft also absorbed completely. In a third case in which a boiled graft was used the graft has made no effort to fuse but persists as an inert sequestrum (Fig. 23). In the fourth case an autogenous graft was used but fracture of the transverse process has enabled it to ride upwards and become disimpacted from the sacrum (Figs. 19 and 20); this graft has become incorporated into the transverse process above and has made a gallant effort to fuse below, but a pseudarthrosis at this end is present and mobility persists. In the final case, in a patient with spondylolisthesis, the only demonstrable error is the implantation of the grafts very medially into the sacrum (Figs. 21 and 22), with probable loss of mechanical stability; although the grafts have partly absorbed, this segment

FIG. 23

Case 18.—Ala-transverse graft of boiled tibial bone. Radiograph a year and a quarter after operation. No incorporation. The graft persists as an inert sequestrum.

is quite stable in mobility films and would certainly have been accepted as a success if direct films did not display the grafts so clearly.

Although it is clearly too early to make extravagant claims for this method, if these technical errors can really explain all five failures, and if a later follow-up confirms incorporation of the grafts in the seven cases of probable fusion, then these results must be considered extremely satisfactory.

In the first six months of this year (1953) a further fourteen patients have been treated by this method. The difficulties of the operation make it impossible to adopt a perfectly standardised technique, but in most of these cases it has been possible to exclude the obvious errors described. Five of these later cases already satisfy the criteria of certain fusion, and all but one of the remainder fall into the probable group. In the one failure, a rather half-hearted attempt at fusion was made by simply wedging a boiled graft between the transverse process and ala; it remains as an inert sequestrum.

CONCLUSIONS

I believe that the conventional methods of posterior fusion after laminectomy are not satisfactory and it is therefore important to search for a better method. I strongly suspect that some of the reported results, especially when the graft has to bridge the gap between L.4 and the sacrum, are not as good as their authors believe, and I believe many surgeons are of the same mind (Armstrong 1952). It was a bitter disappointment to discover that the easy inter-body operation, upon which I had built up great hopes, was of no use, and I hope that the reporting of this rather extensive series of failures will be of some value to future workers in this field.

I have great hopes for the intertransverse method described here, which undoubtedly produces sound arthrodesis in a fair proportion of cases. I believe it is the most promising method yet reported and that, perhaps after further modification or in combination with other techniques, it is likely to give a very satisfactory fusion rate.

SUMMARY

1. The usual methods of posterior arthrodesis of the lumbo-sacral joint are not satisfactory in cases in which laminectomy has been performed.

2. Estimation of fusion by mobility radiographs is unreliable and cannot distinguish between fibrous ankylosis and bony fusion.

3. Bone grafts inserted from behind between the vertebral bodies almost invariably fail to become incorporated.

4. Intertransverse arthrodesis has given promising results and is probably the best method available at present.

I wish to express my gratitude to Mr R. G. Pulvertaft for his help and encouragement during the progress of this work, and to Dr G. Q. Chance for his assistance with its radiological aspects.

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THE PROBLEM OF THE BROKEN JUDET PROSTHESIS

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Arthroplasty of the hip is still in the experimental stage. Workers are still trying to find the ideal procedure for both the relief of pain and the restoration of function. Failure of the hip joint may occur at any age, as a single condition or as part of a generalised joint disease. There can be no one solution to all the multitudes of trouble which we are called upon to treat in the hip.

The first real practical arthroplasty of the hip was the cup operation as devised by Smith-Petersen (1939). The operation was widely used in this country, and I have performed the operation in over a hundred cases. Some did well and some did badly. It was difficult

FIG. 1

FIG. 2

Figure 1—Loosening of prosthesis as shown radiographically. Figure 2—After removal, the prosthesis was found to be broken at its rim.

to foretell before the operation which was to be successful and which a failure. I came to the conclusion that the blood supply of the stump of the femoral neck was the all-important factor in determining the end-result.

When Judet (1950) introduced the acrylic prosthesis it seemed to me that it would provide the answer to many of these problems. It seemed far sounder to get rid of that part of the bone in which the circulation was endangered either by a vascular calamity or by sclerotic changes in the bone itself. I therefore decided to try the Judet arthroplasty in a series of cases.

It became obvious from the beginning that the immediate results were better. The patients were quicker to get on their feet and the range of movement was superior to that after the cup operation. This improvement was apparent, but transient, continuing through the first and sometimes the second year. At about this stage the improvement after the Judet

operation appeared to halt, and complications began to appear. In contrast, the results after the cup operation on the whole continued to improve up to the third year, after which they reached their peak and remained stationary.

FRACTURE OF THE PROSTHESIS

The complications noticed in the Judet operation were a falling off of performance in a previously satisfactory hip, and the gradual reappearance of pain and muscle spasm. The radiograph at this period suggested that the prosthesis was loose (Fig. 1). Then, on watching these cases for several months, occasionally one would come up against a case with a typical fracture of the prosthesis which resembled clinically an intracapsular fracture of the femur. So far I have encountered five broken prostheses in a series of about a hundred cases (Figs. 2 to 4).

The structural breakdown in these cases follows a definite pattern. First the prosthesis becomes loose, then the rim begins to fracture, and finally the stem breaks with the steel insert as well, or the insert remains intact and breaks at a later date. In two cases the fracture was sudden, the insert breaking with the stem. If the disintegration was slow, stages one and two were followed by loss of function, pain and muscle spasm. In stage three there were severe pain and collapse of the leg, and all the signs of an intracapsular fracture of the neck of the femur.

THE PROBLEM AND THE POSSIBLE SOLUTIONS

In discussing the problem of the broken acrylic hip the most important factor to be determined is the magnitude of the problem—its incidence. Next, what is the nature of the substance we are using? Is it reliable or should it be abandoned and should we seek some other solution to the problem of arthroplasty? Is methyl methacrylate the best material for use in the prosthesis?

Disadvantages of methyl methacrylate—The manufacturers claim for it that methyl methacrylate can be given a very high polish. This is true. Even when a prosthesis has been in the body for two years, and when a flat facet has been worn upon it, it still remains smooth. The substance is inert to sodium salts and to organic acids, is a poor conductor of heat and electricity, and is tolerated well by the human tissues. Nevertheless it is not a good substance for a prosthesis for reasons of durability, strength and fatigue.

FIG. 3

Prosthesis removed after one and a half year's use in an old person. Note the marked surface wear.

Surface wear—Firstly, after only one year's wear in an oldish person, there was well marked flattening of the weight-bearing surface. How then can we expect the substance to stand up to a life of activity in an active adult or young person? From its wearing characteristics alone I believe that the operation with the prosthesis has no place in the treatment of the young or middle-aged person with arthritis of the hip, nor should such a prosthesis be used to replace a degenerate head in a patient suffering from Perthes' disease, slipped femoral epiphysis, or fracture of the neck of the femur in a young person.

Breaking strength—Another unfortunate characteristic of methyl methacrylate is the variability of its strength when tested in a breaking machine. Twelve rods, five inches long and nine-sixteenths of an inch in diameter, were deliberately smashed in a machine to record the cross-breaking strain. The rods were individually supported on two V-blocks two and a quarter inches apart, and weight was gradually applied until fracture occurred. Before the test each rod was boiled for thirty minutes and cooled, some quickly and some gradually—it did not make much difference. The least breaking strain was 370 pounds and the greatest 1,230 pounds.

There is an enormous difference, therefore, between the least and the greatest strength. Those with the inserts seemed to be the strongest. The greatest breaking strain when an insert was present was 1,230 pounds and the least was 440 pounds, a difference of about 300 per cent. Without an insert the greatest cross-breaking strain varied between 690 pounds and 370 pounds, a difference of about 180 per cent (Fig. 5).

From these tests it is obvious that the strength of methyl methacrylate is unreliable—so much so, in my opinion, that the material is unsuitable for the manufacture of a hip prosthesis.

Fatigue—Let us now discuss the nature of the fracture. In only one of the five broken heads was there a history of a fall. One patient was in bed, one at the kitchen sink, another swimming, and a fourth just walking. The fracture is clearly a fatigue phenomenon.

Possible improvements—The risk of fracture might be reduced by redesigning the prosthesis. A standard two-inch head with a thick rim would be unlikely to break; and if,

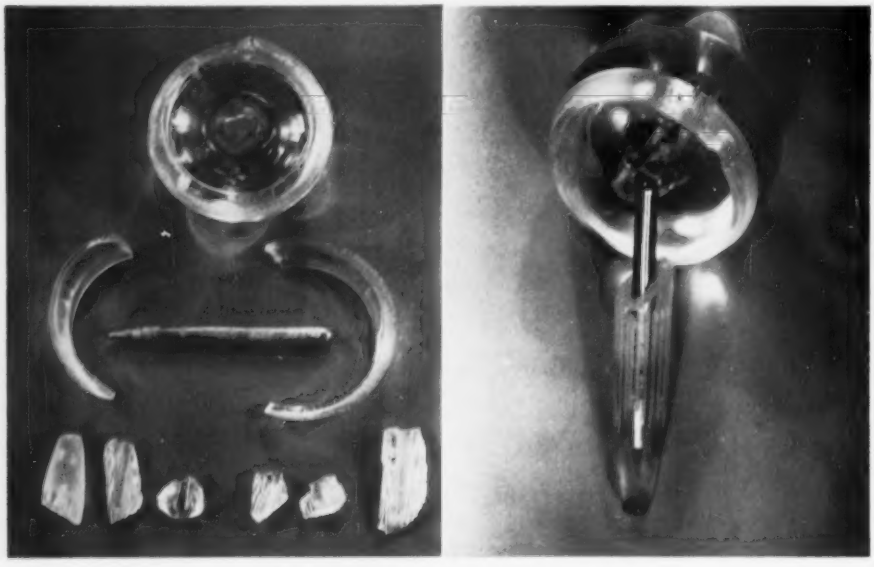

FIG. 4

Various types of fracture of acrylic prostheses.

in the design of the stem, the longitudinal flutes were replaced by ridges, its effective diameter would be increased to eleven-sixteenths of an inch instead of less than half an inch as at present.

A method I have been using to reduce the strain on the prosthesis is to place the acrylic head in a metal cup. This cuts down the strain on the acrylic head by increasing the range of movement and preventing the head from being firmly held by the surrounding fibrous tissue. I have not sufficient cases on which to base a conclusion, but so far the results have been excellent.

DISCUSSION

The studies reported here lead me to the conclusion that the acrylic head prosthesis operation should be abandoned for any patient who intends to lead an active life or to earn his living. The originators of the operation have discovered that it was not universally satisfactory, and they have changed their prosthesis to an oblique-angled femoral head, still made of methyl methacrylate. It is a pity that the original operation was so widely publicised when its defects must already have been known.

Remembering again that arthroplasty of the hip is still experimental, we must not be

disheartened by failures. Eighty per cent of our patients are satisfied and consider that the operation has been well worth while. The operation is, I believe, a good one, but the material of the prosthesis has been found lacking.

Treatment of the fractured prosthesis—Among the large number of cases of Judet arthroplasty already performed in this country it must be expected that fracture of the prosthesis will occur in about 10 per cent, and as time goes on the number might be greater. How then are we to treat these cases? In the early stages, when radiographs show that the stem is eccentric, three months in plaster might allow the prosthesis to gain sufficient fixation with fibrous tissue to afford relief. But if this does not help there is no virtue in waiting until the inevitable fracture occurs. The operation should be revised and a more ambitious

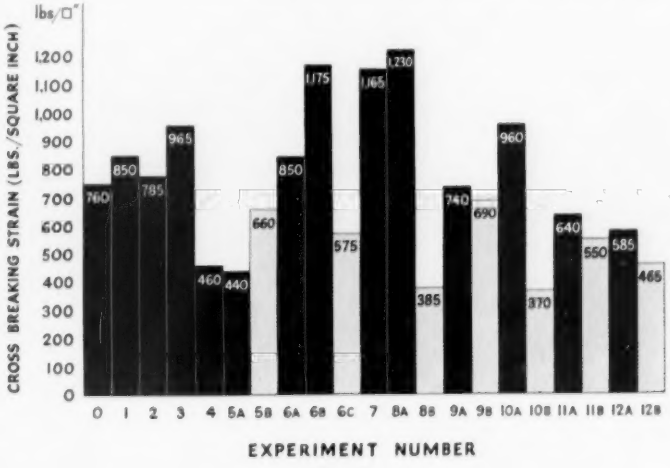

FIG. 5

Results of experiments to determine the breaking strain of rods of methyl methacrylate of uniform size. Black columns—rod with steel insert; stippled columns—rod without insert.

type of prosthesis used, such as that advised by Merle d'Aubigné *et al.* (1951). This apparatus must be very strong, for the leverage on it is powerful. A Küntscher or Watson-Jones nail is not nearly strong enough and will break from fatigue in time. Whatever prosthesis we make it must be extremely strong to withstand long-continued stresses.

An alternative solution in cases of fractured prosthesis lies in the Girdlestone (1945) operation, which has certain merits for this complication. Firstly, it is final and introduces no new foreign substance that may break or come to grief in the body, and no substance which will wear. Another good feature of the Girdlestone operation in such a case is that its usual weakness—that is, instability of the hip—is unlikely to be evident, for there will already be a mass of firm fibrous tissue in consequence of the first operation. On the whole, I think that the Girdlestone operation—that is, removal of the head and neck of the femur—is the most satisfactory answer to the problem of the broken or failed acrylic prosthesis.

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DYSPLASIA EPIPHYSIALIS MULTIPLEX

A Report of Fourteen Cases in Three Families

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This paper reports fourteen cases, in three families, which appear to be examples of dysplasia epiphysialis multiplex, although they differ in some respects from Fairbank's (1946) description.

CASE REPORTS

FAMILY 1

A boy aged six years attended the Connaught Hospital, London, complaining of pain in the left hip. He was small for his age. Radiographs revealed bilateral "fragmented" epiphyses. Inquiry elicited that several members of his family were similarly affected (Fig. 1).

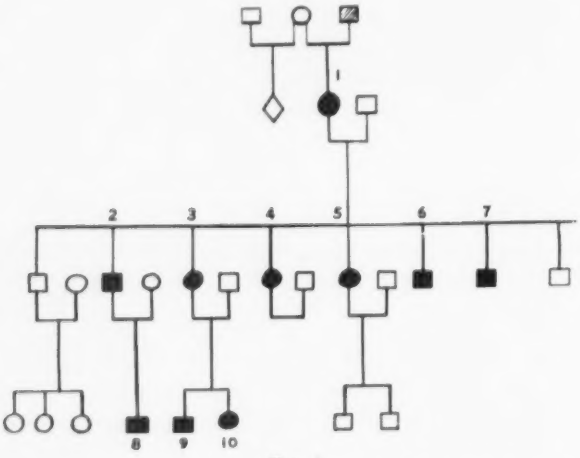

FIG. 1

Family 1. □ = male; ○ = female. Black = affected individuals; white = unaffected individuals; shaded = unknown if affected. Numerals indicate case numbers in this report.

Case 1—Woman aged fifty-eight. She had first noticed pain in her left hip at the age of eleven years, and this continued until she menstruated at fourteen. Thereafter she suffered only occasional discomfort until a few years ago, when both hips became progressively more stiff and painful and chronic low backache occurred. She has otherwise lived a normal and healthy life, and had eight living children and one stillborn. She never complained of pain or stiffness in other joints. She was the only child of her father, who was "short," but her mother had been married before, and had twelve normal children. She was 4 ft. 7 in. in height, had normal intelligence and sexual development, and was a little overweight. When she stood the trunk appeared short and the finger tips reached nearly to the patellae (Fig. 2). There was a mild thoracic kyphosis, with increased lumbar lordosis. She had a waddling gait. At the hips there was 70 degrees of flexion but no other movement. There was some restriction of abduction and medial rotation at the shoulders. All other joints appeared normal.

Radiographic examination—There were changes in many joints. In both hips osteoarthritic changes were associated with a flattened head, a sloping acetabulum, and coxa vara (Fig. 3). There was slight flattening of the humeral head with an underhanging beak and some irregularity in the glenoid fossa (Fig. 4). The lower tibial epiphysis was sloping, with corresponding changes in the talus, but there was no evidence of osteoarthritis.

FIG. 2

FIG. 3

FIG. 4

Case 1. Figure 2—The patient aged fifty-eight. Figure 3—Left hip. Figure 4—Right shoulder.

FIG. 5

FIG. 6

Case 2. Figure 5—The patient aged thirty. Figure 6—Left hip.

Case 2—Man aged thirty, engineer. He was the second son of the patient in Case 1. Though short, he regarded himself as normal. His hip joints felt stiff after prolonged sitting but had never been painful. He was 5 feet in height, with normal intelligence and sexual development. He was very muscular. The trunk appeared short, and the fingers reached to within four inches of the patellae

(Fig. 5). Flexion at both hips was nearly full but rotation was only half normal. The other joints were normal. The hands and feet looked normal.

Radiographic examination—There were osteoarthritic changes in the hips with irregularity of the femoral heads (Fig. 6). In the left ankle there were sloping articular surfaces. All other joints appeared normal.

Case 3—Woman aged twenty-nine, with two children, both of whom were affected (Cases 9 and 10). She noticed pain in the right hip after her first child was born at the age of twenty-two, but has had no pain since. She could walk five miles without difficulty and did her own housework. Her pregnancies were uneventful. She was 4 ft. 8 in. in height. At both hips there was slight reduction of rotation, but other movements were normal. At the shoulder there was slight restriction of medial rotation. There was no carrying angle at the elbows. Hands and feet were normal (Fig. 7).

FIG. 7

FIG. 8

FIG. 9

Case 3. Figure 7—The patient aged twenty-eight. Figure 8—Left hip. Figure 9—Mid-thoracic spine.

Radiographs showed irregularity of the femoral heads, with some flattening (Fig. 8). The shoulders, ankles and knees were normal. The spine showed developmental abnormalities: the thoracic vertebral borders had irregular surfaces, and the body of T.8 was shallow and wedged anteriorly (Fig. 9).

Case 4—Woman aged twenty-six, with no children. She first noticed pain in her hips when she was twelve years of age, but was able to attend school and work as a domestic servant. For the last three years she has had pain in both hips after exercise, and this has restricted her activities. Five years ago she developed pain and swelling in several joints, and a diagnosis of rheumatoid arthritis was made. She was 4 ft. 4½ in. in height (Fig. 10). The long axis of the skull was elongated. Hip movements were nearly full, extension and medial rotation only being reduced. Trendelenburg's sign was positive. There was some stiffness of elbows and wrists (possibly from previous rheumatoid arthritis). Other joints were normal. *Radiographically*, both femoral heads were irregular and flattened; there was marked coxa vara, and the roof of the acetabulum was ill developed (Fig. 11). There was abnormal development of the cervical and thoracic vertebrae (particularly T.5, 6, 7, 9) which were shallow and had irregular surfaces (Fig. 12). There was slight spondylolisthesis at L.5–S.1. The skull showed platybasia (Fig. 13). The lower tibial surfaces were sloping (Fig. 14).

Case 5—Woman aged twenty-four, with two children. In her childhood she had occasional pain in both hips, but subsequently led a normal life, and can still walk five miles. She now has "stiffness" in the hips after exercise or prolonged sitting. She was 4 ft. 11 in. in height. There was a nearly full range of movement at both hips. The other joints were normal (Fig. 15).

Radiographs showed that the right femoral head was flattened medially (Fig. 16). Otherwise the hips showed no marked abnormality. There were mild developmental changes in the thoracic spine, affecting particularly T.6 (Fig. 17).

FIG. 10

FIG. 11

FIG. 12

Case 4. Figure 10—The patient aged twenty-six. Figure 11—Left hip. Figure 12—Cervical spine.

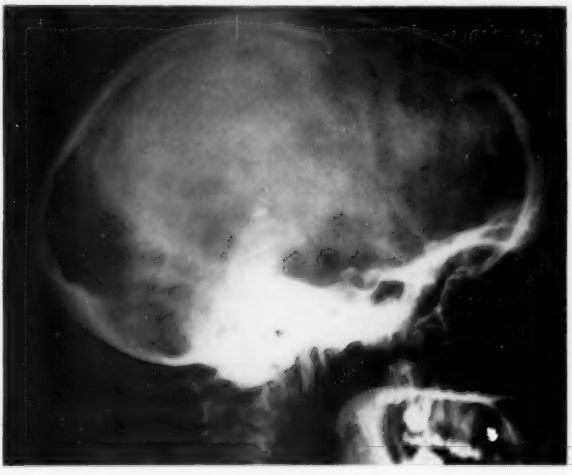

FIG. 13

FIG. 14

Case 4. Figure 13—Skull showing platybasia. Figure 14—Ankle joint showing flattened joint surfaces.

Case 6—Man aged twenty-three, colliery surface worker. He had occasional pain in both hips between the ages of five and ten. Recently he complained of pain in both hips after exercise or prolonged sitting. His height was 4 ft. 11 in. The trunk was short, and the limbs disproportionately long. The fingers reached nearly to the patellae (Fig. 18). Hip movements were slightly restricted,

especially rotation on the right side. *Radiographs* showed that both femoral heads were slightly flattened and of irregular texture (Fig. 19). The lower tibial surfaces were sloping.

Case 7—Man aged twenty-six, unemployed. He suffered pain in the hips after activity when about seven years old, and could not walk more than a mile because of pain and stiffness. Recently

FIG. 15

FIG. 16

FIG. 17

Case 5. Figure 15—The patient aged twenty-four. Figure 16—Left hip. Figure 17—Thoracic spine.

FIG. 18

FIG. 19

Case 6. Figure 18—The patient aged twenty-three. Figure 19—Left hip.

he has suffered pain and stiffness in the hips after sitting or walking. His height was 5 ft. The arms appeared relatively long and the trunk short. The fingers reached nearly to the patellae (Fig. 20). Movements were restricted at both hips, especially rotation. *Radiographically*, the femoral heads were flattened and the roofs of the acetabula were more sloping than normal. Mild coxa vara was present (Fig. 21). Other joints were not radiographed.

Case 8—Boy aged eleven. At six years he developed a limp and pain in the right hip. He was admitted to hospital and traction was applied for a short time. He has since had occasional pain in both hips, and has limped when he was tired. His height was 3 ft. 11 in. His fingers reached to within three inches of the patellae (Fig. 22). Hip movements were nearly full, and all other

FIG. 20

FIG. 21

Case 7. Figure 20—The patient aged twenty-one. Figure 21—Left hip.

FIG. 22

FIG. 23

FIG. 24

Case 8. Figure 22—The patient aged eleven. Figure 23—Left hip, showing sloping acetabulum and epiphysis for femoral head only just appearing. Figure 24—Left ankle.

joints had a normal range. His hands were normal. *Radiographs* of the hips revealed sloping acetabula with femoral epiphyses very late in appearing and "fragmented" (Fig. 23). The lateral half of each lower tibial epiphysis was shallow (Fig. 24).

Case 9—Boy aged four years. He had never had pain in his hips, but had walked with a limp

when tired. His height was 2 ft. 9 in. The upper limbs appeared relatively long, the fingers reaching nearly to the patellae (Fig. 25). There was full mobility of the hip joints. *Radiographs* showed that in each hip the femoral epiphysis was late in appearing (Fig. 26), and then " fragmented "; and there was broadening of the metaphysis. The acetabula appeared normal. The epiphyses for the upper end of the humeri were slightly fragmented (Fig. 27). The lower tibial epiphyses were slightly shallow laterally (Fig. 28).

FIG. 25

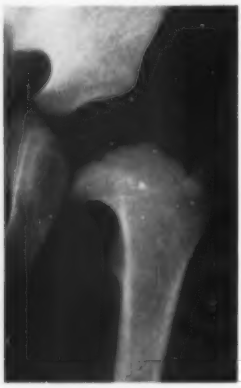

FIG. 26

FIG. 27

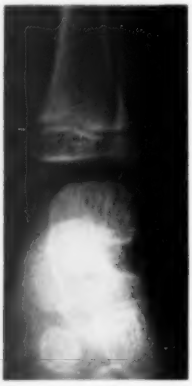

FIG. 28

Case 9. Figure 25—Patient aged four. Figure 26—Left hip. Figure 27—Left shoulder. Figure 28—Left ankle.

FIG. 29

FIG. 30

Case 10. Figure 29—Patient aged three. Figure 30—Left hip.

Case 10—Girl aged three. At one and a half years she had transient pain in the left hip from which she apparently made a complete recovery. She was small for her age, being 2 ft. 9 in. tall (normal 3 ft. 1 in.) but otherwise she was of normal appearance (Fig. 29). All joints were clinically normal. *Radiographs* revealed femoral epiphyses in which irregular ossification produced a stippled epiphysis (Fig. 30).

FAMILY 2

The patients in Cases 11 and 12 were the youngest of four siblings (Fig. 31). The oldest two were not seen but were stated to be normal and free from the complaints of the others. Both parents were dead. The father was stated to have been tall and the mother short, but there was no history of pain in the hips in either.

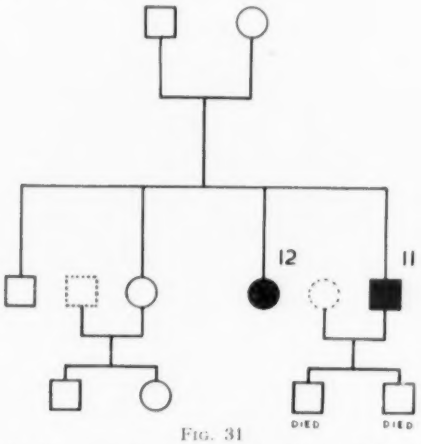

FIG. 31

Family 2. □=male; ○=female. Black=affected individuals; white=unaffected individuals. Numerals correspond with case numbers in this report.

Case 11—Man aged forty-three, now disabled and not working. When fourteen he suffered pain in both hips which prevented games. He continued to have pain and stiffness intermittently, but worked as a lorry driver until he was forced to give this up because of pain and stiffness. He also suffered from pain in the lumbar region, shoulders, knees and ankles. Four years ago he had pain in both wrists and paraesthesia in the hands from compression of the median nerves, which was relieved by division of the flexor retinacula. His two children died in infancy from "asthma" and "pneumonia."

He was thin, 5 ft. 5 in. in height, with relatively long upper limbs which nearly reached to his patellae (Fig. 32). Both hands had stubby digits. The left hip was ankylosed in neutral

FIG. 32

FIG. 33

FIG. 34

Case 11. Figure 32—Patient aged forty-three. Figure 33—Left hip. Figure 34—Left shoulder.

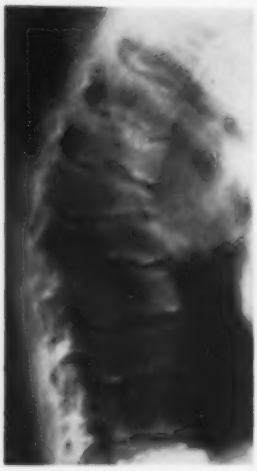

FIG. 35 FIG. 36 FIG. 37

Case 11. Figure 35—Thoracic spine. Figure 36—Left ankle. Figure 37—Part of left hand.

position. At the right hip a moderate range had been restored by arthroplasty. Both shoulders had a restricted range of movement, total abduction being 90 degrees. At the elbows, wrists and ankles movements were slightly reduced. *Radiographs* showed severe osteoarthritic changes in the hips (Fig. 33). The shoulders showed cyst formation, flattening of the infero-medial surfaces of the humeral heads and underhanging beaks (Fig. 34). Some of the vertebral bodies were flattened and wedged, particularly T.6–10 (Fig. 35). The lower tibial surfaces were sloping and the left talus was irregular (Fig. 36). The metacarpal and metatarsal heads were flattened (Fig. 37).

Case 12—Woman aged forty-five. From the age of fifteen she had progressive painful stiffness of both hips, which eventually forced her to give up her work as a packer. She also suffered from pain in her shoulders, knees and ankles. *Radiographs* revealed osteoarthritis in both hips (Fig. 38) and cystic changes in both glenoid fossae (Fig. 39).

FIG. 38 FIG. 39

Case 12. Figure 38—Left hip. Figure 39—Right shoulder.

FIG. 40
Case 13—Right hip.

FIG. 41

FIG. 42

Case 14. Figure 41—Hips. Figure 42—Right ankle.

FIG. 43

FIG. 44

Case 14. Figure 43—Right hand. Figure 44—Left knee.

FAMILY 3

There are two known cases in this family, details of which have been kindly provided by Mr Norman Roberts. The patient in Case 14 has been previously referred to (Fairbank 1947). In view of a possible family history, the father and brother were examined.

Case 13—Man aged fifty, with two children. He suffered pain in the hips and a limp for most of his life. He was short, and had stubby digits. Movement at both hips was restricted. *Radiographs* showed osteoarthritis in both hips, with gross flattening of the femoral heads and acetabula with cyst formation and sloping roofs (Fig. 40).

Case 14—Man aged twenty, the younger son of the patient in Case 13. He had pain in the hips for many years. He was short and had stubby hands. *Radiographs* showed flattening and irregularity of the femoral head and large acetabula (Fig. 41). In previous films (1948) there was deficient development of the lateral part of the lower tibial epiphysis and of both shoulders, knees and wrists (Figs. 42 to 44).

DISCUSSION

Hereditary and familial features—In each of these three families there were two or more individuals affected with this condition. In Family 1 ten out of seventeen members in three generations were affected, including six out of eight siblings (Fig. 1). In Family 2 a brother and sister were affected; further detailed investigation was not undertaken (Fig. 31). In Family 3 a father and at least one son were affected; the rest of the family was not examined. The father was thought by all to be normal until carefully examined and radiographed.

The distribution of the lesions in these three families is not the same, but in each family a similarity could be traced in the affection of its individual members. In Family 1 there was an obvious hereditary influence, but in Families 2 and 3 this was disclosed only after careful inquiry.

Effect on life and function—There is no record of death from the disease in these families. *Infancy*—No abnormality was observed by the parents of any of the children: each child sat up, crawled and walked at the appropriate age. *Childhood and adolescence*—Some of the children complained occasionally of pain in one or other hip, and were unable to walk as far as normal children without tiring. In some cases stiffness in the hips was observed at times, but all these children attended school, and the children of Family 1 participated normally in games. The patient in Case 11, as a child, avoided games on account of pain. No difficulties were encountered when they started work. *Adult life*—The condition, as a rule, eventually caused considerable disability. All the men in Family 1 were engaged in manual work which appeared well within their powers. The man in Family 2 had to give up his work on account of stiff hips.

Pregnancy did not present difficulty in Family 1. In Case 1 the patient had eight children, and the other two women had two each.

Common features. *Dwarfism*—All the affected members of Family 1 were between 4 ft. 6 in. and 5 ft., in contrast to the unaffected father and son who were 5 ft. 6 in. in height.

In Family 2 the two affected members were normal in height—5 ft. 6 in.—though shorter than other members of the family.

The father and son in Family 3 were both said to be short.

Distribution of lesions—In Family 1 the frequency of involvement was, in order: hips, ankles, shoulders, spine, skull. The hands, feet, knees, elbows and wrists were unaffected. In Family 2 the involvement was: hips, shoulders, ankles, hands and spine. The knees, elbows and wrists were unaffected. In Family 3 the involvement was more widespread: hips, shoulders, knees, ankles, hands, feet and elbows. *Hands*—In Families 2 and 3 the hands were stunted and the digits short, stubby and blunt at the ends. Movements and function were full. In Family 1 there was no abnormality in the hands. *Spine*—In some members of Families 1 and 2 the trunk appeared short, and the limbs relatively long (Figs. 2, 18 and 22).

Radiographic appearances—Abnormal features occurred only in the epiphyses in children and the joint surfaces in adults. The hip region was affected in all cases. In the children the

affected epiphyses were late in appearing and backward in development, but fusion was not delayed.

In the adults the lesions varied from a slight irregularity of the shape of the femoral head and acetabular roof to severe coxa plana and irregular acetabula. In no case was subluxation present. Osteoarthritic changes occurred in patients over the age of thirty-five and in one, at least, under that age.

In one of the children (Case 9) there was mild fragmentation of the left upper humeral epiphysis, and, in some of the adults, there was infero-medial flattening of the humeral head and some dysplastic change in the glenoid. At the ankle the lower tibial epiphyses or surfaces were sloping from the lateral to the medial side, and in some there were corresponding changes in the talus.

In the hands and feet of Family 1 there were no abnormalities in the metacarpals, metatarsals or phalanges, whereas in Families 2 and 3 these bones were stunted (Figs. 37 and 43).

Comparison with previously recorded cases—Fairbank (1947) gave the name dysplasia epiphysialis multiplex to a condition characterised by mottling or irregularity in density of several of the developing epiphyses, dwarfism and stubby fingers.

In a collected series of twenty-six cases he found a variety of epiphyses involved: most commonly at the hips, shoulders, ankles and hands; less frequently the knees, wrists and elbows. In only two cases was platyspondyly observed.

Hereditary and familial influences were not marked, though a mother and son, two sisters, and boy twins were affected. Radiographically, the abnormalities in the epiphyses were irregularity in ossification, late appearance, and early fusion. The epiphyses were mottled, sometimes mulberry-like, and appeared to have multiple centres. The upper femoral epiphyses were most commonly affected but only rarely were changes seen in the acetabula. There was flattening in the upper humeral epiphyses, but the glenoid fossae were normal. Fairbank found many variations from this common pattern.

Case 8 of this series showed the features of dwarfism and affection of several epiphyses, but there were no recognisable changes in the hands. A rather unusual feature was the well marked hereditary element (Fig. 1). In the affected members of this family there was a relatively high proportion of cases in which the spine was affected, and in some the dwarfism appeared to be of the short-trunk type.

In Family 2 the two affected members were not markedly dwarfed, but characteristic changes were present in the hips, shoulders, ankles and hands. In Case 11 the spine was also involved and the trunk was relatively short. This might well represent a mild reduction in stature, for some of his family were considerably taller.

In Family 3 both father and son had a similar widespread distribution of lesions, but it is not known whether the spine was affected.

Whereas all these fourteen cases thus showed many of the characteristic features of dysplasia epiphysialis multiplex, there are some discrepancies: 1) the hereditary or familial nature of all the cases; 2) involvement of the spine in some cases, causing a short-trunk rather than short-limb type of "dwarfism" in Families 1 and 2 (3 not known); and 3) the mild nature of the affection in Families 1 and 2. Despite these differences, the characteristic features justify the inclusion of these cases in the condition described by Fairbank as dysplasia epiphysialis multiplex. Fairbank (1947) advised that a child below average height suffering from bilateral pseudocoxalgia should have radiographs taken of the shoulders and ankles to exclude this dysplasia. Similarly, bilateral osteoarthritis of the hips in a short person under the age of forty might suggest examination for multiple epiphysial lesions.

Genetic aspects—In Family 1 at least three generations were affected, and ten individuals out of eighteen had the features of this condition. This points to a genetic basis. The defect appears to be due to a Mendelian unifactorial dominant gene. It is unifactorial because the

affected is clearly distinguished from the unaffected. It is dominant because the ratio approximates to the 1 : 1 ratio expected, and because if recessive it would require that the normal parents marrying into the family were carriers, unlikely in a disease so rare as this. Families 2 and 3 have not been fully investigated, but the occurrence of two cases at least in each family supports the hereditary basis suggested by Family 1.

In previous reported cases there is evidence of an inconstant hereditary basis. Fairbank (1947) collected many cases from those previously classified under different names. Of these, Gardiner-Hill (1937) described two sisters, Barrington-Ward (1912) a brother and a sister, Resnick (1943) a mother and twin boys, Cholmeley (1947) two brothers. Waugh (1952) described the affection in three sisters. Thus twelve reported cases and the fourteen herein described give a familial or hereditary basis in twenty-six out of forty cases.

It is possible that more would have been found to have affected relatives, but many of these individuals do not regard themselves or their relatives as abnormal until complications arise or radiographic examination reveals the condition.

Nature of the affection—The underlying pathology of dysplasia epiphysialis multiplex is a failure of the epiphyses to ossify normally, both in rate and extent. This may express itself in most of the epiphyses or in only a few. The variability in degree and distribution accounts for the diversity of conditions that have been collected under this heading. Some are almost within normal limits whereas others approach the condition described by Morquio and Brailsford as chondro-osteo-dystrophy (Brailsford 1929).

Fairbank (1947) distinguished chondro-osteo-dystrophy from dysplasia epiphysialis multiplex by the characteristic anterior tongue-like prolongations of the vertebral bodies, the angular kyphosis, and the more severe involvement of the epiphyses, particularly the acetabulum. It is worth noting that in Families 1 and 2 there were epiphysial changes in the vertebrae, but no kyphosis and no anterior tongue-like projections. In some members of Family 1 there was slight irregularity of the acetabula.

In gargoylism the dysplastic changes in the epiphyses resemble, more or less, those in Morquio-Brailsford syndrome, but in the former there is involvement of systems other than the musculo-skeletal.

The failure of epiphysial development may also cause other disorders that have not hitherto been classified with dysplasia epiphysialis multiplex, such as " familial brachydactyly associated with bilateral coxitis " (Brailsford 1946).

I am grateful to Mr Charles Gray for his help in the preparation of this paper. I should also like to thank Mr Norman Roberts for permission to include cases 13 and 14, Miss C. Lucas of the Royal Free Hospital School of Medicine for her advice on the genetic aspect, and Mr J. Sheppard for the photographs.

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SUPRACONDYLAR FRACTURES OF THE HUMERUS IN CHILDREN

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Two types of supracondylar extension fractures of the humerus are seen in children. About one-third have little or no displacement and present no serious problem. The rest are grossly displaced and may be difficult to treat. This paper deals only with this latter type.

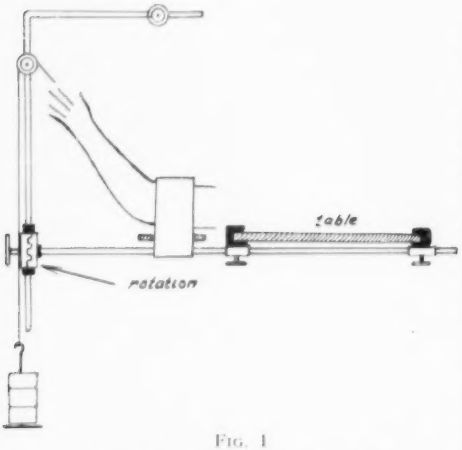

FIG. 1
Attachment for applying traction.

Three conditions must exist to secure a good result: an exact reduction, a safe fixation, and careful and prolonged after-care. Remodelling of the humerus (newly debated by Attenborough 1953) may give better movements than originally expected but does not correct the grave varus deformities (such as that shown in Attenborough's Figure 14). The author is of the opinion that all means should be used and eventually new methods devised to obtain satisfactory reduction and safe fixation.

Many surgeons have advised open reduction, Holmberg (1942) representing Scandinavia in this respect, but it is usually admitted that open reduction may be difficult and is frequently followed by a decreased range of movement.

An important problem is rotational displacement of the lower fragment resulting in bad contact, secondary displacements and varus deformity.

Böhler (1938) advised reduction under pronation but this is not sufficient in all cases. Philippides (1937) advised reduction by means of mechanical traction and this proved to be of great value. Persson (1938) constructed a handy frame for this purpose. Certain difficulties were experienced, however, even with this method. The author presented (1939) the results of treatment with mechanical traction combined with strong lateral rotation of the arm and followed by fixation, including the shoulder. The results were definitely improved by this method.

Fixation with a plaster cylinder from the fingers to the upper part of the arm does not prevent rotation, and secondary displacement will frequently occur in the plaster. The forearm rests on the abdomen in medial rotation. This directly invites a new rotational displacement. The author considers it necessary to include the shoulder in the plaster. The old rule still holds good: the joints on both sides of a fracture must be immobilised when using plaster-of-Paris for fixation.

FIG. 2
Position of limb in plaster.

DETAILS OF TREATMENT

Reduction—All means must be available and used individually as need arises. These include: 1) mechanical traction; 2) lateral rotation during the traction; 3) varying pronation and flexion of the elbow; and 4) direct manipulation.

An easy way of applying traction is to use a bundle of knitting wool as a sling around

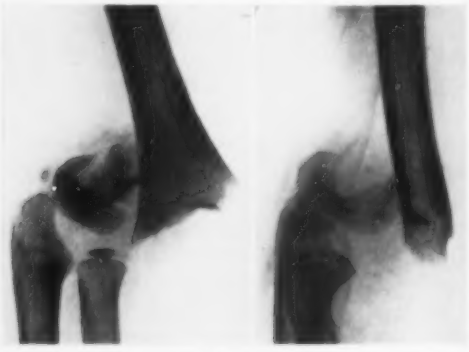

FIG. 3

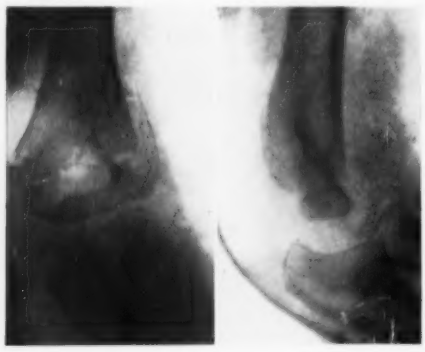

FIG. 4

Case 1. Figure 3—Before reduction. Figure 4—After reduction, in plaster.

the base of each finger and to tie them to a simple bow. Perssons (1938) frame is not effective in some cases which demand extreme rotation. The author (1939) prefers an extension apparatus that permits traction by means of weights in all degrees of rotation (Fig. 1). Very often the arm has to be maximally rotated in such a way that the hand is behind the frontal plane ("hurrah position").

Like many surgeons (Windfield 1948) the author avoids extreme flexion of the elbow because of the danger of producing ischaemia of the forearm and hand. For this reason reduction and fixation are carried out with the elbow at 135 degrees or sometimes flexed to

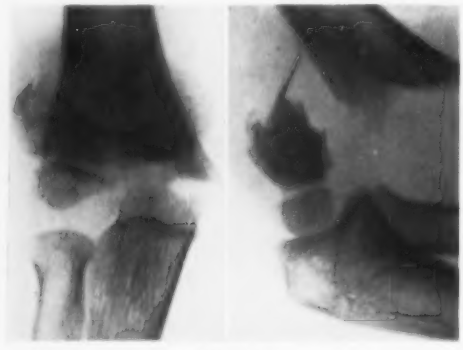

FIG. 5

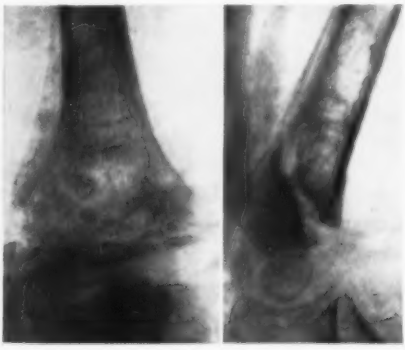

FIG. 6

Case 2. Figure 5—Before reduction. Figure 6—After reduction, in plaster.

90 degrees. Using the 135 degrees position, it is possible to simplify the traction: it is only necessary to pull on the hand and to put counter-traction on the arm just above the elbow (Fig. 1). The patient is fixed to the table. When the traction has been working for a little while reduction is carried out by manipulation. If check radiographs show rotational

displacement the arm is rotated laterally while the traction is continued. This is important because without the traction the lower fragment may catch the upper one and reduction does not take place. The degree of lateral rotation is varied according to the radiographs. Fluoroscopy makes this procedure easier. There are times when the pronation of the forearm or the flexion of the elbow must be altered. In one case reduction was obtained only when lateral rotation was used with the elbow in full extension and the hand in pronation.

If patience and great care are used, these methods will result in satisfying positions in at least 90 per cent of all cases and in the remaining 10 per cent there will be only an occasional bad result.

Fixation—A plaster shoulder spica is applied while traction is maintained and with the arm in lateral rotation (Fig. 2). The holes caused by the traction materials may be filled afterwards. If severe swelling exists or if the child has eaten shortly before the accident and it is unwise to give anaesthesia, a preliminary reduction may be carried out, an arm plaster put on and

FIG. 7

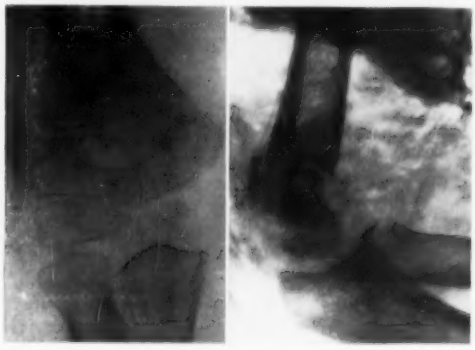

FIG. 8

Case 3. Figure 7—Before reduction. Figure 8—After reduction, in plaster.

the arm suspended above the head of the child in the bed in such a way that the arm is kept safely in lateral rotation. The final reduction is carried out one week later, and a plaster spica applied as described.

After-treatment—The only treatment has been by active movements within the limits of pain, the children being carefully instructed and the movements supervised. The author has seen some very bad results (stiff elbows) after passive movements and massage (Watson-Jones 1943).

RESULTS

Thirty fractures with gross displacement have been treated according to the description and followed up for three to eight years. Most of them have been examined more than six years after the injury. The children were aged between two and eleven years. Illustrative radiographs are shown in Figures 3 to 8.

Anatomical results—The accuracy of the reduction as determined by radiographic examination is shown in Table I.

Only one result, with 25 degrees' varus, was considered bad. This case was one of Y-fracture, comminuted and involving the joint, and it might have been discarded from this material of supracondylar fractures.

Clinical results—Functionally twenty-four of the thirty children had ideal results with a normal range of movements, normal appearance and no complaints. Four children had a

normal range of movement but a varus deformity measured on the arm to 5, 8, 9 and 15 degrees. One of these was admitted to the hospital with a radial paralysis. Neurolysis was performed and full recovery followed. One child had a flexion defect of 10 degrees and a varus angulation of 7 degrees. One had 35 degrees lack of extension and 25 degrees of varus (intra-articular Y-fracture).

TABLE I

ANATOMICAL RESULTS IN THIRTY CASES OF SUPRACONDYLAR FRACTURE OF THE HUMERUS

Displacement	Number of cases
Displacement less than 2 millimetres	22
Ulnar displacement (8 millimetres) .	1
Radial displacement . . .	2
Dorsal displacement . . .	1
Varus angulation	4
Rotational displacement . .	0

I have compared these results with a series of supracondylar fractures treated by manipulative reduction and arm plaster (Jensenius 1948) and a series treated with open reduction and arm plaster (Holmberg 1942). This comparison is seen in Table II.

TABLE II

COMPARISON OF RESULTS OF THREE METHODS OF TREATMENT

	Manipulative reduction and arm plaster (Jensenius)	Open reduction and arm plaster (Holmberg)	Traction in lateral rotation and shoulder spica (Madsen)
Cases . . .	75	54	30
Results* (per cent)			
Good . .	43	61	83
Fair . .	40	22	10
Bad . .	17	17	7

* Good = full movement, varus not exceeding 5 degrees
Fair = loss of movements by up to 10 degrees, varus 5–10 degrees
Bad = loss of movement by more than 10 degrees, or varus exceeding 10 degrees

COMMENT

The importance of varus deformity—I agree with Windfeld (1948) and other surgeons who consider rotational displacement as an important cause of varus deformity. Ulnar displacement and angulation may give the same result. In two cases an increase of a very slight varus deformity has been observed from disturbance of growth at the epiphysial line. A disturbance of this nature has not occurred in any case with perfect reduction. This observation is considered to encourage the attempt to obtain perfect reduction.

SUMMARY

1. Reduction of supracondylar fractures in children by lateral rotation of the arm combined with mechanical traction and manipulations is described. Fixation in a plaster shoulder spica is recommended.
2. The results are presented and seem to be satisfactory.

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TUBERCULOSIS OF THE GREATER TROCHANTER*

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This review deals with thirty-eight patients with tuberculosis of the greater trochanter treated throughout or partly at the Royal National Orthopaedic Hospital during the last twenty-five years. In thirty-five cases the diagnosis was confirmed by culture, histology or guinea-pig inoculation. In the other three cases we considered that the clinical and radiographic findings justified their inclusion in the series. Pyogenic osteomyelitis of the trochanter, the alternative diagnosis in these patients, is uncommon and has distinctive radiographic features.

We are primarily concerned with the results of the various forms of treatment that were used. We have concluded that complete excision of a tuberculous trochanter, an operation that has been widely practised, is unsatisfactory. Spread of tuberculosis to the hip joint, a complication in eight of our patients, appears to have a relationship to this procedure.

Classification—We agree with previous writers who have classified the disease into two forms, bursal and osseous, the bursa referred to being the large gluteo-femoral bursa, which lies on the postero-lateral aspect of the lower part of the trochanter.

Fig. 1

Typical destruction of bone on the lateral aspect of the trochanter.

Lindahl (1952) and Ahlberg (1948) believed that the primary lesion might be either a bursitis or an osteitis. Alvik (1949) considered that the primary lesion was always a bursitis, osteitis being secondary to it. McMurray (1947) stated that a peripheral bony erosion signified secondary osteitis. We believe that either lesion may be primary; in some cases there was tuberculous bursitis with no evidence of osteitis, whereas in others, characterised clinically by a painful swollen bursa of short duration, there was osteitis of such an extent that it must have been present much longer.

The typical osseous lesion (Fig. 1) causes destruction, generalised rarefaction and sequestration, all of which are readily seen in good radiographs. (The encysted type of tuberculous lesion that is sometimes seen at the base of the femoral neck in children is not included in this review because the lesion does not cross the epiphysial line of the trochanter.)

Age incidence and associated lesions—Thirty of the thirty-eight patients were first seen between the ages of ten and forty years. Three cases occurred in the first decade. Only five patients were over forty (Table I).

Seventeen patients had had other tuberculous lesions before the onset of trochanteric disease, five had concomitant lesions, and three developed other lesions later.

* Paper read at a meeting of the British Orthopaedic Association in London, October 1954.

TREATMENT

To assess the various forms of treatment, we have divided our cases into two main groups—those treated conservatively and those treated by operation. Chemotherapy was used in several of the more recent cases, mainly as an adjunct to other measures; in only one patient was it the only treatment used. Multiplicity of treatment has sometimes rendered assessment difficult.

Conservative treatment—Under this heading are considered aspiration of abscesses, with or without immobilisation, and chemotherapy. This group includes patients who had no

TABLE I

INCIDENCE IN RELATION TO AGE

Age in years	Bursal infection	Osseous infection	Total
1–9		3	3
10–19	1	9	10
20–29	2	9	11
30–39		9	9
40–49		3	3
50–59		2	2

specific local treatment. In all, eight patients received conservative treatment for the primary lesion. Two received no treatment and had discharging sinuses for many years. A tuberculous trochanter was found in an out-patient attending for review of her tuberculous spine. Shortly after this she developed a pleural effusion and was confined to bed for several months, during which the trochanteric lesion became quiescent; it has remained so for the last five years. Four patients were treated in a plaster hip spica: in two, the lesions have remained quiescent for eight and ten years; in the third, the disease recurred eleven years later; and in the fourth there was recrudescence of the disease fifteen months after the completion of treatment. Another patient received " ambulant supervision " and developed an abscess two years later. A prolonged period of rest followed by gradual resumption of walking resulted in fifteen years' of quiescence in another instance. A patient who received streptomycin and P.A.S. only, without general or local treatment, suffered a recurrence fifteen months later (Table II).

Fifteen patients with recurrences were treated conservatively. Of these, ten had further recurrences, a sinus persisted in one, and two became quiescent; one is untraced. The remaining patient was undergoing conservative treatment for sinuses which persisted after complete excision of the trochanter. At the time of this treatment it was found that the hip joint was involved.

Operative treatment—The operations undertaken ranged from incision of abscesses or the curettage of sinuses to excision of the whole greater trochanter (Fig. 2). In all, fifty-five operations were carried out, twenty-nine for the primary lesion and twenty-six for recurrences. Thirteen patients received specific chemotherapy at the time of operation. Table III gives the details of the operations and the results, which will be discussed later.

One important fact emerges from a study of this group. We have already mentioned that tuberculosis developed in the hip joint in eight of our patients; in seven it developed after the operation of complete excision of the greater trochanter. Thirteen patients with disease of comparable severity were treated more conservatively, and in none of these did this complication occur.

Chemotherapy—Streptomycin and para-amino-salicylic acid were used in sixteen cases. Although we have a general impression that their use with or without isonicotinic acid hydrazide accelerates the closure of sinuses, expedites primary healing after operation, and reduces the incidence of recurrences, our findings are not conclusive. Excision of part of the trochanter, combined with chemotherapy, seems to have been effective in the five cases in which it was used, but the average follow up is only just over two years (Table III). There also appears to be a place for the combination of aspiration and chemotherapy in patients with an abscess, even though there may be a bony focus of disease.

TABLE II
RESULTS OF CONSERVATIVE TREATMENT

Type of treatment	Primary disease				Recurrences			
	Bursal infection		Osseous infection		Bursal infection		Osseous infection	
	Number of cases	Results	Number of cases	Results	Number of cases	Results	Number of cases	Results
Chemotherapy							1	Quiescent for 8 months
Aspiration							1	Recurrence in 3 months
Aspiration plus chemotherapy			1	Quiescent for 15 months				
Immobilisation	1	Recurrence in 11 years	3	1 Recurrence after 15 months 2 Quiescent for 8 years and 10 years			1	Recurrence in 1 year
Immobilisation plus chemotherapy							1	Followed in 4 months by curettage
Other methods			3	3 Quiescent for 5 years, 15 years, 2 years			3	2 Recurrences in 1 year and 3 years 1 Quiescent for 3 months and then untraced
No treatment			2	Recurrent sinuses in both			8	6 Recurrences 1 Arthritis of hip 1 Persistent sinus
Totals	1	Recurrence	9	6 Quiescent cases. 3 Recurrences			15	1 Quiescent case 10 Recurrences 1 Persistent sinus 1 Arthritis of hip 1 Untraced 1 Followed by curettage

INVOLVEMENT OF THE HIP

Spread of tuberculosis to the hip occurred in eight of our cases (22 per cent), a rather higher incidence than is usually quoted. In all our patients it followed surgical treatment—in seven excision of the entire trochanter had been carried out. In the eighth patient there was extensive tuberculous involvement of the upper part of the trochanter, extending to its medial surface and to the floor of the digital fossa. A bony sequestrum was removed. The hip became manifestly tuberculous seven years later. By this time the trochanteric lesion was quiescent but there was much calcified debris above the femoral neck.

The time intervals between excision of the trochanter and hip joint involvement are set out in Table IV. In Case 21 excision of the trochanter was followed twenty years later by

FIG. 2

FIG. 3

Figure 2—Total excision of the greater trochanter for tuberculosis. The osteotomy extends to the attachment of the capsule on the superior aspect of the neck. Figure 3—Extending calcified debris above the femoral neck with early involvement of the hip joint. The same case as Figure 2, three years later.

extensive "saucerisation" in the region of the base of the femoral neck. This intervention came close to the capsular attachment and was followed in two years by disease in the joint.

Thirteen patients in this series had disease of comparable severity, as judged by clinical and radiological evidence. They were all treated by less drastic methods, and, with one exception, their hip joints have remained normal. The duration of observation has been from three to eighteen years, the average being eight years.

There is no general agreement about the route of joint infection; nor has any definite relationship between complete excision of the trochanter and hip joint involvement been established. Ahlberg (1948) stated that it was liable to occur after repeated or extensive operations in the trochanteric region, and discussed several possible routes of infection. Lindahl (1951) stated that direct bony spread to the hip joint was rare and quoted four cases in which the disease began as a capsulitis. In all our cases it manifested itself originally as a tuberculous synovitis; we could find no instance of spread up the femoral neck into the joint.

The capsular attachment with its synovial lining approaches the digital fossa. We believe that, in our seven patients whose hips became involved after excision of the trochanter, surgical manoeuvres in this critical area may have provided a route for infection of the synovial membrane. In another case complicated by joint disease radiographs had shown an increasing collection of calcified debris lying above the femoral neck (Fig. 3). The gradual extension of calcified shadows in this region denotes continued activity of the disease in the soft tissues; this may progress even when the osteitis is quiescent, and—as happened in this particular patient—arthritis may follow.

When arthritis developed many years after operation, the possibility of an independent infection could not be excluded. But in none of our patients did the opposite hip become the seat of the disease.

RECURRENCES

Tuberculosis of the greater trochanter has been truly described as a disease characterised by a marked tendency to recurrence. To establish criteria of cure is impossible, because even

TABLE III

RESULTS OF OPERATIVE TREATMENT

Type of Treatment	Primary disease				Recurrences			
	Bursal infection		Osseous infection		Bursal infection		Osseous infection	
	Number of cases	Results	Number of cases	Results	Number of cases	Results	Number of cases	Results
Incision or excision of sinus or bursa	2	1 Recurrence at 1½ years. 1 Recurrence at 14 years	12	2 Quiescent, 8 years and 9 years. 10 Recurrences at 2, 2, 2, 3, 3, 4, 11, 14, 25 and 35 years	1	Quiescent at 22 years	2	2 Recurrences at 3 and 5 years
Above plus chemotherapy					1	Quiescent at 3 years	2	Quiescent at 4 and 6 months
Excision of sinus and curettage of diseased bone			8	1 Quiescent at 7 years. 6 Recurrences at 6 months, 2, 3, 4, 5 and 33 years. 1 Hip involved at 6 years			7	2 Quiescent at 6 and 9 years. 4 Recurrences at 4, 7, 7 and 4 years. 1 Hip involved at 2 years
Above plus chemotherapy			1	Quiescent at 2 years			3	2 Quiescent at 3 and 4 years. 1 Recurrence at 6 months.
Partial excision of trochanter			1	Not traced			2	Recurrences at 2½ and 4½ years
Above plus chemotherapy			1	Quiescent at 2½ years			4	Quiescent at 3, 3, 3 and 1½ years
Total excision of trochanter			4	3 hips involved at 1, 2½ and 24 years. 1 Recurrence 20 years			3	3 Hips involved at 5, 6 and 15 years
Above plus chemotherapy							1	Recurrence at 3 years
Totals	2	2 Recurrences	27	5 Quiescent. 17 Recurrences. 4 Hips involved. 1 Untraced	2	Quiescent	24	10 Quiescent. 10 Recurrences. 4 Hips involved

TABLE IV

HIP JOINT INVOLVEMENT

Case	Age at onset of trochanteric disease (*years*)	Primary treatment	Treatment of recurrence	Interval between last operation and hip involvement
1	23	Removal of sequestrum		6½ years
2	29	Excision of trochanter		23 years
9	52	Excision of trochanter		11 months
17	33	Excision of trochanter plus streptomycin		3 years
21	16	Excision of trochanter	Saucerised 20 years later	2 years
24	29	Excision of abscess	Excision of trochanter	6 months
29	17	Removal of sequestrum	Excision of trochanter	5 years
32	8	Excision of abscess	Excision of trochanter	15 years

when the disease has become quiescent clinically and radiologically it is quite likely to recrudesce. In four of our patients there was recrudescence after more than twenty years of quiescence. Nevertheless, most recurrences have occurred within five years.

Thirty-nine recurrences were treated, fifteen by conservative means and twenty-four by operation (Tables II and III). Of the patients treated conservatively, ten had further recurrences, one had persistent sinuses, one required operation after four months, one remains symptomless eight months after the completion of treatment, and one is untraced. The remaining patient in this group was being treated conservatively for sinuses after excision of the trochanter when tuberculous arthritis developed. Thus it may be seen that conservative treatment of recurrences is unsatisfactory.

Of the twenty-four patients treated surgically, twelve have remained healed, but the time of follow up in some is short (Table III).

CONCLUSIONS

The difficulties in assessing the various forms of treatment for this disease have been referred to, and to draw several hard and fast conclusions would be misleading. We believe, however, that total excision of a tuberculous trochanter should be avoided. Moreover, when any operation is undertaken for this condition, the medial aspect of the trochanter should be treated with the greatest respect.

The results show that for the primary disease the best treatment is probably by aspiration of abscesses (repeated as necessary) combined with chemotherapy. Immobilisation in a hip spica for three months is also to be recommended. Operative treatment of the disease in its early stages has been followed in many of our cases by a sinus which closed slowly and often recurred, sometimes after an interval of many years; but to what extent this picture may be altered by chemotherapy we are unable to say. For the recurrent sinus or abscess after surgical intervention, further operation is required, for conservative measures generally fail in these cases. Excision of the sinus tracks, bursa and diseased bone under chemotherapeutic cover is recommended for this type of case. Rest in bed for three months, and possibly also immobilisation in a hip spica, appear to be sound.

SUMMARY

1. Thirty-eight cases of tuberculosis of the greater trochanter have been reviewed.

2. Classification into bursal and osseous infections is discussed, and reasons have been given for our belief that either lesion may be the primary one.

3. An attempt has been made to assess available methods of treatment. In general, conservative measures are recommended for primary lesions, and surgery for recurrences. We have the impression that chemotherapy is of definite value.

4. The incidence of spread of tuberculosis to the hip joint is discussed. In this connection, reasons have been given for condemning excision of the trochanter.

We wish to thank Mr H. J. Seddon, Mr J. I. P. James and Mr F. C. Dwyer for their help with this paper, and the surgeons of the Royal National Orthopaedic Hospital for making these cases available.
We are grateful to Miss Beryl Crosby for her secretarial assistance and to Mr R. J. Whitley for providing radiographic prints.

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DISLOCATION OF THE CARPAL SCAPHOID

Report of a Case

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A blacksmith aged thirty-six attended the casualty department with an injury of his right wrist. He was cycling over a narrow bridge when he collided with another bicycle coming in the opposite direction. On examination, the wrist was moderately swollen and tender over its radial aspect. All movements were greatly restricted and painful.

Radiographs showed that the scaphoid had been rotated so that the proximal pole, which normally articulates with the radius, had been dislocated to the lateral side of the radial styloid process and the distal end had been moved in front of the capitate (Fig. 1). The capitate, trapezoid, trapezium and first three metacarpals had closed up towards the radius, whereas the other carpal and metacarpal bones remained in their normal positions. A small chip fracture of one of the carpal bones lay between the capitate and the radial styloid.

Treatment—Under general anaesthesia the scaphoid was easily reduced by forced deviation of the hand to the ulnar side with digital pressure over the displaced scaphoid. A plaster back splint was applied. Further radiological examination showed that the scaphoid was reduced to its normal position (Fig. 2). Radiographs three weeks later showed that the scaphoid had not undergone any ischaemic change; and on clinical examination the swelling was minimal, tenderness was slight, and half the full range of active movement was present.

Fig. 1
Initial radiograph.

The wrist was enclosed in plaster-of-Paris for a further three weeks, at the end of which time the swelling and tenderness were absent, and movement was only slightly restricted. The radiological appearance was again normal. Two weeks later the patient returned to heavy manual work without any disability. When last seen eighteen months after the injury he was free from disability and the range of wrist movement was full.

Comment—Isolated dislocation of the carpal scaphoid is a rare injury. The considerable force that is necessary to squeeze out the scaphoid more usually results in a fracture of the radial styloid or of the waist of the scaphoid than in the dislocation of the scaphoid.

In most reported cases the dislocation has been caused by injury while the hand was gripping something in ulnar deviation and dorsal extension of the wrist. Thus in the case reported by Walker (1943) the man was cranking a van which backfired, and Kuth's (1939) patient was a street car driver involved in a crash while holding the knob of the control handle, which was sufficiently violent to break off the handle in his hand. Russell (1949) reported a case like the present one in a motor cyclist, and in two other cases, those reported by Buzby (1934) and Andrews (1932), the patients were involved in accidents while driving motor cars; in Andrews' case the ulnar styloid process was also fractured.

The force is transmitted up the second and third metacarpals through the capitate to the scaphoid. If the hand is not in ulnar deviation the sudden dorsiflexion that takes place results in the more common transcarpal retrolunar dislocation of the capitate with a fracture or dislocation of the scaphoid.

FIG. 2
Position immediately after reduction.

Treatment should be aimed at reducing the dislocation as soon as possible, because the earlier it is done the more likely it is to succeed; within a week of the injury the bones become glued together with serous exudate. In most cases it has been possible to reduce the dislocation by direct pressure over the scaphoid while traction is applied to the fingers, usually with the wrist extended. Only in a few cases has open reduction been necessary, usually when there has been delay in attempting the reduction. The ease with which the reduction was effected in the present case was probably due to the fact that only one hour had elapsed between the injury and manipulation. Watson Jones (1929) condemned the use of levers between the articular surfaces as being likely to result in osteoarthritis. In Walker's case (1943) closed manipulation four days after the injury failed. At open operation the tenseness of the ligaments made the operation so difficult that the scaphoid had to be severed from its attachments; after being washed in saline it was replaced and the torn capsule was sutured over it. Revascularisation of the bone took place with an excellent functional result.

In long-standing cases arthrodesis or excision of the scaphoid will be necessary. It is interesting that in none of the cases reported has there been any evidence of permanent avascular necrosis.

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DISLOCATION OF THE FIFTH CARPO-METACARPAL JOINT

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Isolated dislocation of the carpo-metacarpal joint of the little finger is rare. The fifth carpo-metacarpal joint is less mobile and more protected than the corresponding joint of the thumb, dislocation of which is fairly common, especially in association with Bennett's fracture. A similar injury occurs in the fifth carpo-metacarpal joint, and about twenty cases have been described. There is medial and proximal displacement of the bone, and there may be a fracture of the lateral part of the base, the smaller fragment remaining in its normal position. As in Bennett's fracture-dislocation, the deformity is maintained by muscle pull, in this case the flexor carpi ulnaris acting through the piso-metacarpal ligaments, and continuous traction has been found necessary to secure stable reduction. One such case has been seen recently.

Dislocation with antero-lateral displacement of the metacarpal base across the palmar surface of the neighbouring metacarpals is an injury of much greater rarity. Reference to only four cases has been found, and the present case appears to be the first diagnosed immediately after injury. All have been caused by direct violence to the ulnar side of the hand. In all, closed reduction was found to be impossible, and open reduction has been performed.

McWhorter (1918) described a case in a man of twenty-three. The dislocation was diagnosed two weeks after the injury. After an extensive dissection, reduction was achieved and found to be stable. Good function resulted.

Buzby's case (1934) occurred in a woman of forty-eight from forcibly turning the steering wheel of a car. During open reduction one month later incisions on the palmar and dorsal surfaces of the hand were required, the dislocation was reduced, and the metacarpal base sutured in position with catgut. There was residual weakness of grip.

Roberts and Holland (1936) mentioned a radiograph of such a case, but gave no clinical details.

Watson-Jones (1943) described this injury in a policeman of twenty-eight who had fallen from a motor cycle. Seven weeks after the injury an incision was made over the ulnar border of the hand, and the bone was pulled into place with a blunt hook. The joint surfaces were so eroded that arthrodesis was performed. The hand recovered normal function.

CASE REPORT

The patient was a joiner of sixty-nine. Both his hands were already stiff from arthritis, and he had had a severe infection in the right hand in his youth, with the result that this was the stiffer hand. When crossing the road he was struck from behind on the ulnar border of his right hand by a motor cycle. On admission to Wembley Hospital he complained of severe pain along the ulnar side of the hand. In spite of the displacement (Fig. 1) the hand differed surprisingly little from the normal. There was a half-inch long laceration on the dorsal surface, and the whole hand was swollen. This swelling, together with extreme tenderness, masked the presence of the metacarpal base in the palm, and its absence from the hypothenar eminence. With the fingers held in semi-flexion, the little finger appeared merely to be abducted slightly. This appearance probably accounts for the delayed diagnosis in the previous cases. When, however, the finger was flexed, it was found to point not at the tubercle of the scaphoid, as is usual, but towards the distal end of the metacarpal bone of the thumb. This appearance of the flexed finger was most striking. Function of the ulnar nerve was normal.

Radiographs showed a dislocation of the carpo-metacarpal joint, with the base of the metacarpal displaced anteriorly and laterally, lying in front of the base of the third metacarpal. There were two tiny flakes of bone apparently avulsed from the medial side of the base.

Manipulative reduction failed. Preparation was therefore made for open reduction.

Operation—Two days after the injury an incision was made along the ulnar border of the hand, the hypothenar muscles were displaced forwards, and an attempt was made to pull the bone back into place with a blunt hook. This proved difficult, and it was supposed that such a blind manoeuvre might endanger the deep branch of the ulnar nerve. The small laceration on the dorsum was therefore excised, and this opening enabled the handle of a scalpel to be used to lever the bone into place. The reduction was unstable because all the ligaments attached to the metacarpal base were ruptured. A hole was therefore drilled in the medial part of the base, and a catgut suture was passed through this from the dorsal incision, and brought back via the medial incision through the ligaments on the medial side of the hamate, constructing a new medial ligament. Non-absorbable material was not used

FIG. 1
Initial radiograph.

FIG. 2
Six weeks later.

because of the laceration on the dorsum of the hand. Both skin incisions were closed and the hand was immobilised in plaster with the flexed little finger pointing towards the tubercle of the scaphoid.

Progress—Active movements of the other fingers were started immediately. After ten days the sutures were removed, and the little finger was immobilised in semi-flexion. Immobilisation was discontinued after a further four weeks (Fig. 2) and active movements of all fingers were started. Recovery of movement was very slow as the whole hand had previously been stiff, and the grip was at first weak. The patient returned to his work as a joiner five months after the injury.

When he was finally discharged a month later the movements of the fingers were still not full, but he stated that they were as good as before the accident. The grip was strong and there was no tenderness over the affected joint. The normal antero-posterior movements of the fourth and fifth carpo-metacarpal joints were full and painless and there was no instability.

DISCUSSION

With the exception of the first, there is not a great deal of movement in the carpo-metacarpal joints. The second and third are virtually immobile, and on them depends the strength of the hand. There is a small amount of antero-posterior movement in the fourth joint, and more in the fifth, so that the fifth metacarpal is capable of moving through about 15 degrees. These are accessory movements which are important for the function of the hand. They bring about the normal cupping of the palm when grasping a rounded object, and assist in opposition of the little finger. Flexion of the fourth and fifth metacarpals occurs also when the fist is clenched in firm gripping. Arthritis in these joints therefore interferes with the mobility of the hand, and weakens the grip. This was the main complaint of the present patient before recovery was complete, and was the residual disability in Buzby's case.

It seems probable that the correct treatment for such a dislocation is early open reduction, with reconstruction of the ligaments. If reduction is undertaken some time after the injury when the joint surfaces are damaged, it should be followed by arthrodesis, as described by Watson-Jones, in order to prevent persistent pain and weakness.

SUMMARY

Descriptions of four previous cases of antero-lateral dislocation of the fifth carpo-metacarpal joint are reviewed and a further case is reported. Suggestions are made on treatment.

I wish to thank Mr A. J. Cokkinis for permission to report this case, and Mr David Trevor for his help and advice in the preparation of the paper.

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THE OS TRIGONUM

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In 1882 Shepherd reported three cases of fracture of the posterior process of the talus, which he had found while working in the dissecting room. In each case the fragment of bone consisted of the posterior part of the tubercle of the talus lateral to the groove for the tendon of the flexor hallucis longus, and had attached to it the posterior fasciculus of the lateral ligament of the ankle joint. Shepherd believed that the fragment of bone was pulled off by this ligament and tried to reproduce the fracture by forcibly manipulating several ankle joints in the anatomy room, but failed in his attempts. He dismissed the idea that the small ossicle he had found could be due to an ununited epiphysis, for the talus developed from one centre and he had never seen a secondary centre. Turner (1882) pointed out that the occasional existence of a distinct ossicle representing the posterior border of the talus, ascribed to a fracture by Shepherd, was known to anatomists, and he demonstrated a case of a separate ossicle which had a groove in it for the tendon of the flexor hallucis longus. He quoted several authorities who had described the ossicle. Gruber had reported its presence in 1864 and described it as a talus secondarius. Stieda (1869) had mentioned its presence in the left foot of a man. Both Stieda and Gruber regarded the ossicle as representing a modification in development, the talus in these cases having two centres of development. Turner therefore believed that this ossicle owed its origin not to a fracture of the talus but to a secondary centre of ossification for the posterior part which had not fused with the general body of the bone. Bardeleben (1885) considered the accessory talus met with in the human tarsus to be an example of a distinct os intermedium tarsi. The os intermedium tarsi he regarded as homologous with the carpal lunate bone and he called it the os trigonum, the talus of the higher mammals being composed of this os trigonum fused with the general mass of the talus. There is still no unanimity among anatomists as to the origin of the talus in the evolution of the tarsus, the only definite agreement being that it is a compound bone phylogenetically (Schaeffer 1941). Bennett (1887) reported that he had met with this small ossicle in the dissecting room and had always regarded it as a fracture, but after reading the articles by Shepherd, Turner and Bardeleben he was inclined to modify his views, while still believing that it could occur as a fracture of the tubercle of the talus. He quoted a case in which he had found the ossicle separate on the right side, whereas on the left side there was a deep groove marking off the tubercle from the rest of the bone although there was not a complete separation. In his opinion these two examples showed clearly that the meaning of the deep notch was the tendency to the development of a separate ossicle.

Moullin (1901) had seen on several occasions a separate ossicle immediately behind the posterior border of the talus. In one case a severe sprain had occurred and the presence of the os trigonum suggested the possibility of a fracture as well. Keith had informed him that the bone was found as a separate ossification centre in 3–4 per cent of subjects, but he believed that it might be more frequent. Like Shepherd and Bennett, he believed that the tubercle could be pulled off by the posterior fasciculus of the lateral ligament of the ankle. Discussing rarer ossifications seen radiographically, Holland (1921) pointed out that the posterior part of the talus was drawn out normally into a projection and might show very prominently. The os trigonum, when present, was situated at the back of the upper surface of the talus and might simulate a fracture of this projecting piece of bone. He had no doubt that it was a distinct ossicle. It had not been known ever to give rise to symptoms. The true

bone was usually symmetrical and should be seen in the other foot. Bizarro (1921) found the os trigonum present in seven out of 100 feet radiographed. It was often difficult to determine from the radiographs whether the bone was entirely separate or not. Meisenbach (1928) described a fracture of the os trigonum in a patient who fell while playing squash rackets. He believed that the os trigonum appeared more frequently than was recognised and that its fracture was not unusual. Köhler (1935) noted the confusion that this small bone had given rise to, among both clinicians and anatomists. When first seen it was believed to be a fracture, but when attention was drawn to the fact that it was an inconstant accessory bone every broken-off posterior process of the talus was taken for an os trigonum and the presence of a fracture denied, even when the process was typically fractured and the healthy foot was normal. He distinguished the two conditions as follows: if one found behind the talus a shadow in both feet—round, oval or three-cornered—it was an os trigonum; but if there was a smaller triangular shadow separated by a narrow indistinct space from the rounded-off posterior process, it was a fractured process, especially if the healthy foot showed a process without a line of fracture. He noted that fracture of the process was not rare, especially in active adults. Iusem (1948) found radiographs of little value in distinguishing a fractured os trigonum, except when subsequent union occurred. He found that the ossicle was not always bilateral and therefore this feature could only be of relative diagnostic value. Often after a true fracture a condition indistinguishable from an os trigonum had been found.

THE TALUS IN THE CHILD

Examination of the adult talus shows that its posterior aspect consists of two tubercles between which lies the groove for the tendon of the flexor hallucis longus muscle. The lateral tubercle is usually the larger, and it is commonly referred to as the posterior process, although

FIG. 1
Rounded posterior margin of the talus in a girl of six.

not infrequently the medial tubercle may be just as large. The tubercles vary considerably in size, from small processes hardly discernible in the lateral radiograph to the prominent posterior projection mentioned by Holland. Attached to the lateral tubercle is the posterior fasciculus of the lateral ligament of the ankle joint; the deltoid ligament runs backwards to the base of the medial tubercle.

Secondary ossific centres in childhood—In early childhood the posterior border of the talus is rounded and not drawn out into a projection as in the adult (Fig. 1). Secondary centres of ossification for the processes appear at the posterior margin between eight to eleven years of age, depending on the development of the child. They quickly unite with the main bone—usually within a year of their appearance (Figs. 2 and 3).

FIG. 2

FIG. 3

Figure 2—Secondary centres of ossification in a boy of ten. Figure 3—Within the ten-month period of observation the centres had united.

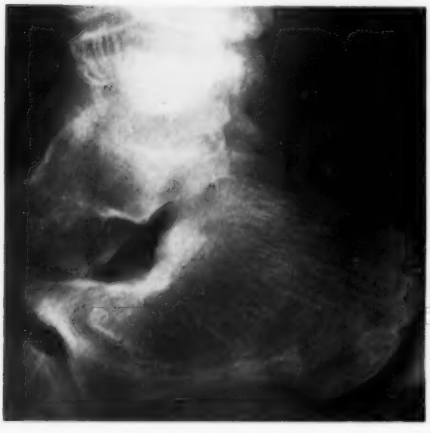

FIG. 4

FIG. 5

Figure 4—Two large discrete centres in a boy of nine. Figure 5—Within five months the centres united to form the two posterior tubercles.

So variable are these centres in size, time of appearance and union, that they may easily be overlooked in radiographs. In thirty-five unselected radiographs of young children's ankles evidence of these centres was found in twenty-nine. One centre only may be seen in each ankle, but frequently two are present, corresponding with the medial and lateral tubercles (Figs. 4 and 5). The size and degree of development may vary in the two ankles. If the

FIG. 6

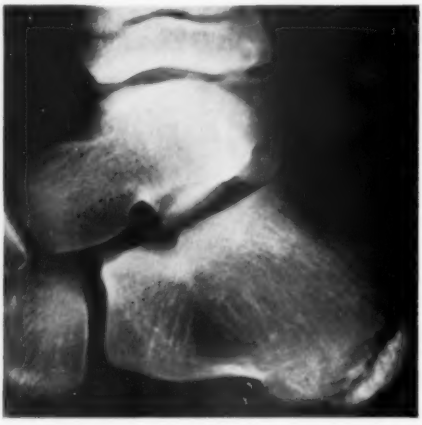

FIG. 7

Figure 6—Two large centres in a boy of ten and a half. Figure 7—Two small centres overlapped by the shadow of the fibula in a boy of nine.

projection is not a true lateral the shadow of the fibula may overlap and conceal them (Figs. 6 and 7).

The statement that the appearance of these secondary centres of ossification is usual conflicts with the views of other writers that such centres appear only occasionally and that when a centre does appear it is liable to remain ununited and form the separate ossicle or os trigonum, found in numbers variously estimated at from 3 per cent (Moullin 1901) to 11·4 per cent (Köhler 1935).

POST-TALAR OSSICLES IN THE ADULT FOOT

That separate ossicles are found in some adult ankles is an established fact and an explanation of their presence must be sought.

FIG. 8

FIG. 9

Figure 8—Normal locking of the ankle joint in equinus produced by the back of the talus striking the tibial margin. Figure 9—Method of kicking a football with the foot in equinus.

Detachment of ossicle by repeated minor injury—When the ankle joint is fully plantar-flexed the posterior aspect of the talus strikes the posterior margin of the tibia and limits the range of movement (Fig. 8). To quote Lambrinudi (1927): "The normal locking of the

ankle joint in full equinus is produced by the posterior tubercle of the astragalus [talus] coming in contact with the posterior margin of the articular surface of the tibia. This is a natural bone block." The Lambrinudi drop foot operation is based on this principle. In an active person the posterior aspect of the talus must strike the posterior margin of the tibia many times each day, and if the tubercles are large they will strike against the tibia and be compressed there by the calcaneum. This repeated impingement of the tubercle against the

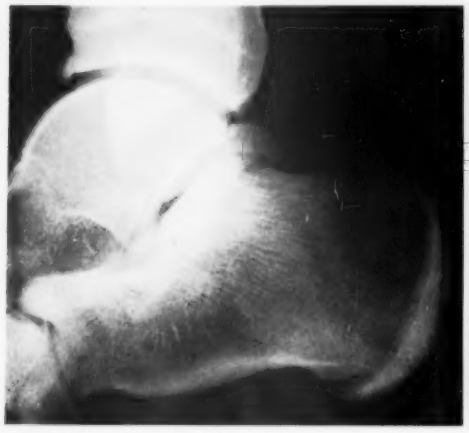

FIG. 10

FIG. 11

Prominent posterior tubercles in a football player aged twenty-one. In the right one (Fig. 10) a translucent line can be made out at the base of the process.

FIG. 12

FIG. 13

Both tubercles show signs of commencing separation. Footballer aged twenty-four.

tibia will lead first to a groove at the point of contact and eventually to separation of the tubercle from the body of the talus. As the process is a gradual one symptoms will be minimal.

Clinical cases—The manner in which the tubercles become separated and the various stages in the process of separation were first noted in a number of football players, some of whom were complaining of symptoms; the others were examined incidentally. McMurray (1950) described how a football is kicked with the foot in equinus (Fig. 9) in order to control its

direction, and he noted that the strain of the blow is borne largely by the anterior ligament of the ankle. It should be added, however, that the locking mechanism described above must come into play, thus subjecting the tubercles to a degree of controlled trauma against the tibia.

Both ankles of the player whose radiographs are reproduced in Figures 10 and 11 show prominent posterior tubercles. On the right side there is the suggestion of an early line of separation; the left is intact. Another football player, who kicked equally well with either foot, complained of pain in the posterior aspect of the ankles when kicking the ball. Radiographs showed lines of separation through both posterior tubercles (Figs. 12 and 13). Both tubercles were removed with complete relief; at operation on each side the posterior fasciculus of the lateral ligament was found attached to the fragment.

A third player complained of pain behind the right ankle, and a rounded separate ossicle was seen behind the talus (Fig. 14). In the left ankle, which was symptomless, a small loose ossicle was present and a definite line of separation was noted at the base of the prominent

FIG. 14

FIG. 15

FIG. 16

Figure 14—A rounded separate ossicle is present in the right ankle. It was removed subsequently at operation. Figure 15—In the left ankle a small loose ossicle can be made out above the more prominent tubercle which is in the process of separating. Figure 16—Left ankle five years later. The prominent tubercle in this ankle has now separated.

posterior process (Fig. 15). At operation the ossicle was removed from the right ankle. It had no ligamentous attachments and resembled a disc-shaped loose body. Five years later both ankles were symptomless, but the process of separation had extended a stage further in the left ankle (Fig. 16).

In another player examined incidentally rounded separate ossicles were present in both ankles; there were no symptoms attributable to the separated processes (Figs. 17 and 18).

These cases illustrate the various stages in the process of separation. The first case shows a line of cleavage in one process. In the second case both processes are beginning to separate. The third case corresponds to the one quoted by Bennett in which he found a separate ossicle in the right foot and a deep groove in the left one. In the fourth player both processes are quite separate. A separate ossific process has also been observed in a woman who had a drop-foot resulting from poliomyelitis in childhood, and in whom the talus was constantly impinging against the back of the lower end of the tibia.

Detachment of ossicle by sudden violence—The example quoted by Turner of a separate ossicle consisting of both tubercles and the groove for the tendon of the flexor hallucis is likely to have been due to a more severe form of injury. A man of fifty-three who had fallen from a height and injured his ankle demonstrated such an ossicle (Fig. 19). When the foot was placed in equinus the point of contact of the process against the tibia could be visualised

(Fig. 20). The patient was not seen until several weeks after his injury and at the first examination this fractured process was regarded as an os trigonum.

When the prominent process is subjected to sudden uncontrolled violence—as when the heel catches on a step while going downstairs—it is fractured with immediate symptoms of pain and tenderness deep to the tendo calcaneus. A patient injured his ankle in this way falling from some steps. The fracture line was plainly visible (Fig. 21), and no doubt would

FIG. 17

FIG. 18

Rounded separate ossicle present in both ankles of a footballer aged twenty. Both ankles symptomless.

FIG. 19

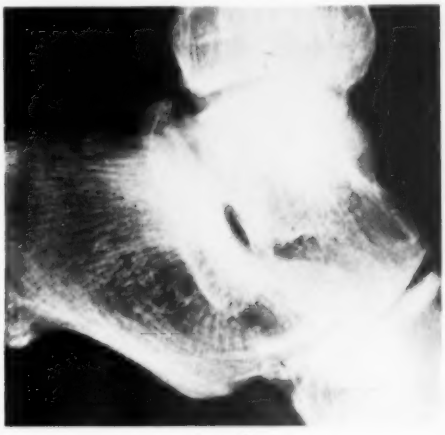

FIG. 20

Figure 19—Posterior part of talus consisting of both tubercles and groove for the flexor hallucis longus tendon broken off by an injury. Figure 20—Foot in equinus to show point of contact with the tibia.

exist about the diagnosis if such a case were seen early. This patient was treated by a plaster for ten days, and thereafter by a supporting bandage, and he returned to work after three weeks. Two years later there were no symptoms referable to the fractured process. Radiographs showed, however, that not only had the small fragment of bone failed to unite, but the edges of the fracture line had become smoothed off, the fragment had altered its shape and the appearance no longer suggested a fracture, but was characteristically that of the so-called os trigonum (Fig. 22).

PERSISTENCE OF A SECONDARY CENTRE AS A SEPARATE OSSICLE

In an active young person a secondary centre may occasionally be prevented from uniting with the body of the talus. A boy of fourteen reported with an injury to his left leg, sustained while playing football. Behind the talus there was a rounded ossicle (Fig. 23); in the right

FIG. 21

FIG. 22

Figure 21—Fracture of the left posterior tubercle in a man of forty-one who fell down some steps. The line of fracture is clearly seen. Figure 22—Two years later the tubercle is quite separate, the fracture line has smoothed off, and the tubercle is becoming more rounded. The appearance does not now suggest a fracture.

FIG. 23

FIG. 24

Figure 23—Left ankle of a boy of fourteen who sustained an injury playing football. A small rounded ossicle is present with a line of demarcation from the talus. Figure 24—After immobilisation in plaster the processs has undergone bony union.

ankle the posterior process was complete. A below-knee plaster was worn for four weeks. When it was removed the ossicle had united with the main bone (Fig. 24) (several oblique views confirmed the union). In this case the ossicle had probably not been separate but had been united to the talus by a synchondrosis.

CONCLUSIONS

From this study the writer believes that secondary centres of ossification for the posterior part of the talus are a normal feature. Owing to their situation and liability to injury against the articular margin of the tibia, the centres may in the first instance be prevented from union, but this happens infrequently. Köhler noted that the incidence of the so-called os trigonum increased with age but could offer no explanation of this fact. It is logical to believe that the process of separation is more likely to have been completed with the advance of years. The separated processes may not be so harmless as other writers have suggested. In five cases operative excision of the fragment was considered necessary for the relief of symptoms.

SUMMARY

1. Previous papers on the subject of the os trigonum are reviewed.
2. Evidence is produced to show that the posterior part of the talus normally develops from separate centres.
3. An explanation is given for the presence in adults of separate ossicles (the so-called os trigonum) in one or both ankles and for the variety of shapes adopted by them.
4. Contrary to opinions expressed by previous writers, these ossicles may give rise to symptoms.

I wish to thank Mr J. Patrick for permission to report these cases, and Mr M. White for allowing me to examine radiographs of children under his care.

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SKELETAL SARCOMATA AND GIANT-CELL TUMOUR

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There is no universal agreement on a classification of bone tumours. Many of the existing methods are based on varying criteria and consequently the nomenclature is confused. Numerous descriptive terms are employed to denote only minor and irrelevant differences in essentially similar tumours.

If a classification is to be more than an academic exercise, the diagnosis of a particular type of tumour, after adequate biopsy, should convey an impression of its probable behaviour and likely response to treatment. The importance of these principles has been stressed by Scarff (1947).

The most widely used classification of bone tumours was that adopted by the American College of Surgeons in 1928. This regarded all primary malignant tumours as osteogenic (arising from bone) sarcoma. The subdivisions of this group were: medullary and subperiosteal, telangiectatic, sclerosing, periosteal and fibrosarcoma, and parosteal. These appear to be purely arbitrary divisions based on descriptive terms assessed by varying methods including clinical, anatomical, radiological and naked-eye appearance, with little regard to the cellular pattern of the tumour. The chondrosarcomata were later separated from this large group (Ewing 1939) and other minor modifications instituted.

Geschickter and Copeland (1949) recognised chondrosarcoma and osteogenic (arising from bone) sarcoma. The latter group is apparently subdivided, mainly on radiological appearances, into osteosclerotic and osteolytic types. To quote these authorities: " If facilities for frozen sections are not available and consultation is required in the diagnosis the roentgenograms and not the sections should be sent, as a diagnosis can usually be obtained roentgenologically without the necessity of a preceding exploration if the proper authorities are consulted " (p. 206). This subdivision of the osteolytic and sclerotic types is an artificial separation depending entirely upon whether a tumour produces sufficient bone to be recognisable in a radiograph; in practice this has little prognostic value as their five-year survival figures were 16 and 21 per cent respectively.

In Great Britain a classification based on cellular appearances has been in use for many years (Scarff 1937). The terms chondrosarcoma, fibrosarcoma and spindle-cell sarcoma have proved valuable largely because they are self-descriptive and histologically accurate.

Much confusion still exists on the meaning of the term osteogenic sarcoma—whether it implies " bone-forming " or " arising from bone." Ewing used the term to denote a tumour arising from bone, but subsequent authors have altered the implications of the word to suit their own conceptions. At present most histologists in this country use the term to indicate bone formation within a tumour.

It is, however, fundamentally important to appreciate that the osteogenic (bone-forming) sarcoma is not itself a pure histological entity. Most types of bone tumour can undergo ossification, but, as will be shown in subsequent sections of this paper, it is not the mere presence of bone that is prognostically significant: it is the method of its formation. Bone formed by tumour cells—tumour bone formation or osteoblast sarcoma—carries a grave prognosis; bone that is merely laid down on the preformed cartilaginous or collagenous matrix of a tumour affects neither the diagnosis nor the general prognosis of that tumour.

If, therefore, in a histological classification, bone formation *per se* is emphasised, it may cause a relatively benign ossifying cartilaginous tumour to be regarded as highly malignant.

The " osteogenic " (bone-forming) sarcomata can readily be subdivided into three histologically recognisable entities: osteosarcoma (osteoblast sarcoma), ossifying chondrosarcoma, and ossifying fibrosarcoma. In our classification the word " osteogenic " in all its diverse meanings has been purposely omitted. The term osteosarcoma (osteoblast sarcoma) is used to denote an easily recognisable and specific tumour entity which is in no way synonymous with osteogenic (bone-forming) sarcoma.

MATERIAL

In order to reassess the value of the histological subdivision of bone tumours we have collected all cases of primary skeletal sarcoma and giant-cell tumour seen at the Middlesex Hospital since 1925. Only those cases with adequate clinical data and histological material have been used. Tumours arising from non-skeletal tissue in bone, such as haemangio-endothelioma, Ewing's tumour and the malignant reticuloses, have been excluded. One hundred and seventy-nine cases remained for analysis. The available pathological material of every patient was re-examined and the tumours have been classified as follows:

PRIMARY MALIGNANT SKELETAL TUMOURS:

Osteosarcoma (osteoblast sarcoma).
Chondrosarcoma.
Fibrosarcoma.
Spindle-cell sarcoma.
Giant-cell tumour.

This is a purely histological classification and relies solely on the cellular pattern of the tumour. It is founded on the method proposed by Scarff (1937) and used in the Bland-Sutton Institute of Pathology since then. Macdonald and Budd (1943) and Lichtenstein (1952) have adopted classifications based on similar principles.

OSTEOSARCOMA

(Osteoblast sarcoma)

This is the most highly malignant group of the primary skeletal sarcomata. Histologically it forms a readily recognisable and specific tumour in which osteoid tissue is produced directly by malignant osteoblastic tumour cells with no intermediate matrix. A histologically accurate term is osteoblast sarcoma and, as previously stressed, it is not synonymous with " osteogenic " (bone-forming) sarcoma.

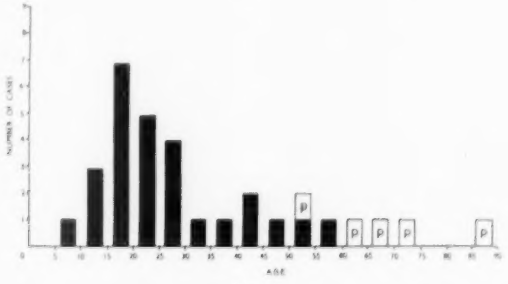

FIG. 1

Age incidence of osteoblast sarcoma. P denotes Paget's disease.

There are thirty-two examples of this tumour in the present series, five of which were associated with Paget's disease.

Age—More than a third of the tumours were observed between the ages of fifteen to twenty-five, and nearly two-thirds between ten and thirty (Fig. 1). Of the seven tumours occurring in patients over fifty, five were known to be associated with Paget's disease.

FIG. 2

FIG. 3

Osteoblast sarcoma of humerus. Radiograph of the specimen (Fig. 3) shows sclerosis of the primary tumour in the mid-shaft of the humerus. There are two sclerotic secondary deposits in the head of the humerus.

FIG. 4

FIG. 5

Osteoblast sarcoma of humerus. Radiograph of the specimen (Fig. 5) shows a relatively osteolytic example of this type of tumour.

Sex—Twenty-one of the thirty-two patients were male and eleven female. Four of the five cases associated with Paget's disease were in men.

Sites—The sites of origin of the tumours are shown in Table I. About two-thirds of the tumours arose in long bones, and half of these were in the region of the knee.

TABLE I

SITES OF OSTEOSARCOMA (THIRTY-TWO CASES)

Femur		**Humerus**	
Upper end	3	Upper end	5
Middle	2	Middle	3
Lower end	8	Lower end	—
		Ilium	4
Tibia		**Skull**	1
Upper end	3		
Middle	—	**Jaw**	1
Lower end	—		
		Spine	1
Fibula	—	**Foot**	1

Length of history—The commonest presenting symptoms were aching pain and swelling. Except in the cases complicating Paget's disease, in which the onset of the tumour symptoms was difficult to assess owing to other skeletal symptoms, the average length of history before attending hospital was three months, and the longest nine months.

Macroscopic appearance—The affected bone is expanded by a solid tumour, the cut surface of which shows visible or palpable bony areas. The bone cortex is eroded, and there is early penetration of the periosteum with involvement of the adjacent soft tissues. Variations in the macroscopic appearance of individual tumours are immaterial to the general behaviour and prognosis of an osteoblast sarcoma.

The macroscopic and radiographic appearance of both the osteolytic and osteosclerotic forms of this tumour may be closely mimicked by other primary bone tumours, and even by secondary deposits of carcinoma (Fig. 14). Although most examples of osteoblast sarcoma have a characteristic appearance, the final diagnosis must always rest with the histology.

Microscopic appearance—The tumour is composed of malignant osteoblastic cells. Microscopically the diagnostic feature is the presence of irregular spicules of osteoid tissue formed and surrounded by malignant osteoblastic tumour cells which often show marked cellular variation and pleomorphism.

The spicules of osteoid tissue are sharply outlined and appear partly refractile; they stain a homogeneous pink with haematoxylin and eosin. In areas these spicules may fuse to form bony trabeculae, but the amount of definitive bone formed varies; the radiographic appearance of the osteosarcoma may, therefore, be either osteosclerotic or osteolytic.

There is usually no cartilage in this tumour, but its presence does not exclude the diagnosis. The specific diagnostic feature of the osteoblast sarcoma is that osteoid tissue is formed directly by the malignant osteoblasts with no intermediate matrix of cartilage or fibrous tissue. This process appears, therefore, to be the malignant counterpart of normal subperiosteal new bone formation, and of simple repair callus.

In spite of the apparent differentiation of the malignant osteoblastic cells in that they produce osteoid tissue, and the histological similarity between this tumour and repair callus (Figs. 11 to 13), the osteoblast sarcoma is, nevertheless, the most highly malignant tumour of bone.

Treatment—Thirteen of the thirty-two patients were treated by radical surgery alone,

including two in whom the tumour was associated with Paget's disease. Eleven patients received radiotherapy alone, including three with Paget's disease. Eight patients were treated by a combination of irradiation and radical surgery.

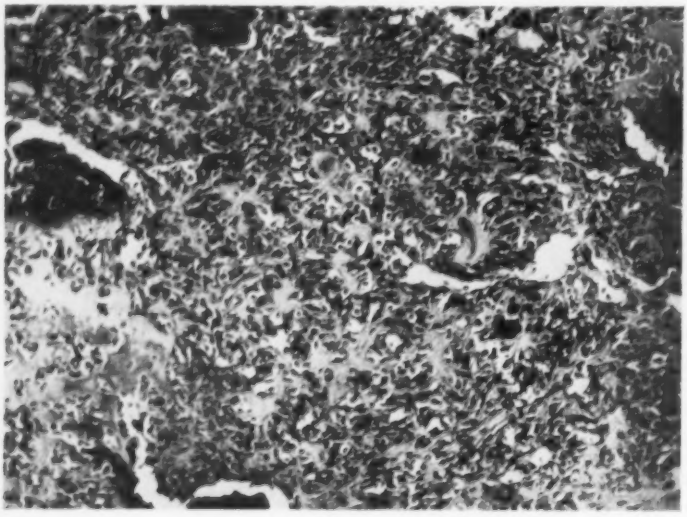

FIG. 6
A low power view of an osteoblast sarcoma with irregular bone formation. (×100.)

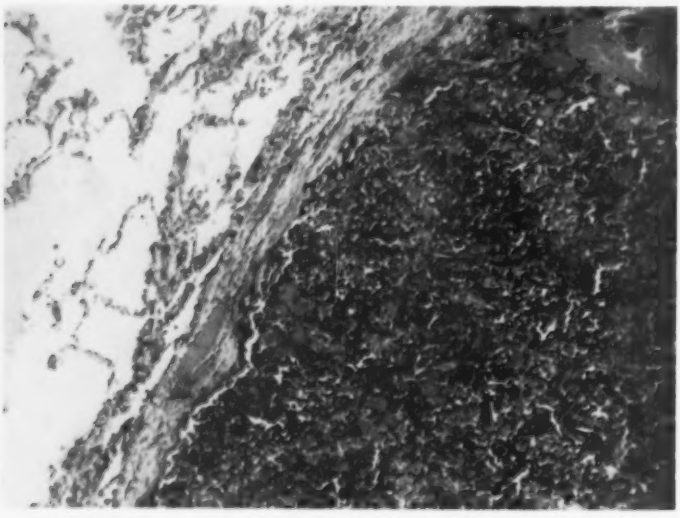

FIG. 7
A secondary deposit of osteoblast sarcoma in the lung. (×100.)

Prognosis—Three-quarters of the patients with osteoblast sarcoma in this series died within a year of treatment (Fig. 10). Only four patients were alive three years after diagnosis; two have lived for three years (one has pulmonary secondary deposits), the others have survived seven and ten years respectively.

The two patients who have survived three years were both treated by radiotherapy alone; one recently had a hindquarter amputation and histological examination at the site of the irradiated tumour revealed no recognisable tumour cells; this patient remains well.

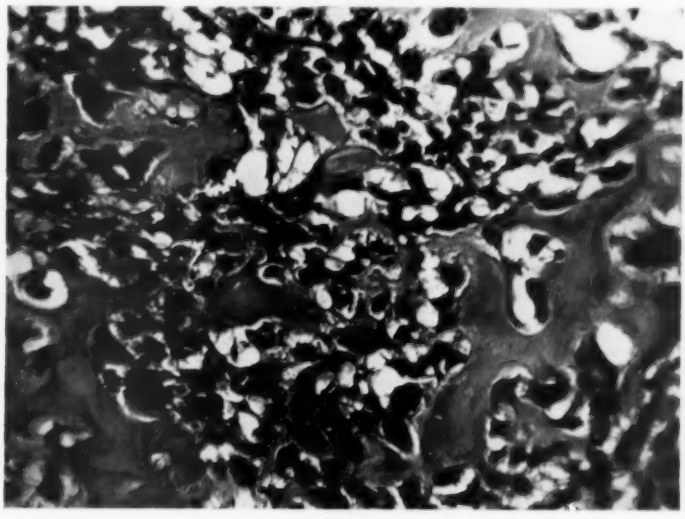

FIG. 8

A high power view of an osteoblast sarcoma with malignant osteoblasts surrounding osteoid spicules. (× 400.)

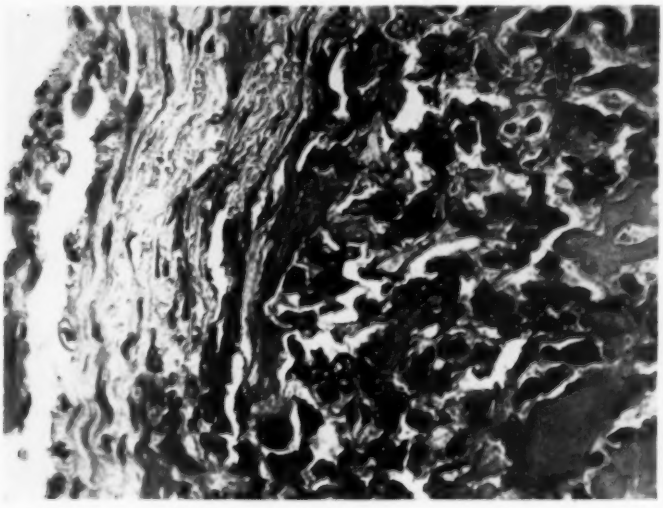

FIG. 9

A high power view of an osteoblast sarcoma in the lung. (× 400.)

The other has had no subsequent surgery but has developed a local recurrence and pulmonary metastases.

The patient surviving seven years had an osteoblast sarcoma at the upper end of the humerus treated by pre-operative irradiation followed by a forequarter amputation. This

patient remains free from recurrence as does the ten-year survivor who was treated by hind-quarter amputation, during pregnancy, for an osteoblast sarcoma at the upper end of the femur.

Metastases—In at least twenty of the twenty-eight fatal cases the patient is known to have had secondary deposits in the lung at the time of death. Three further patients had evidence of metastases in other bones. Many of the patients died outside hospital and, since post-

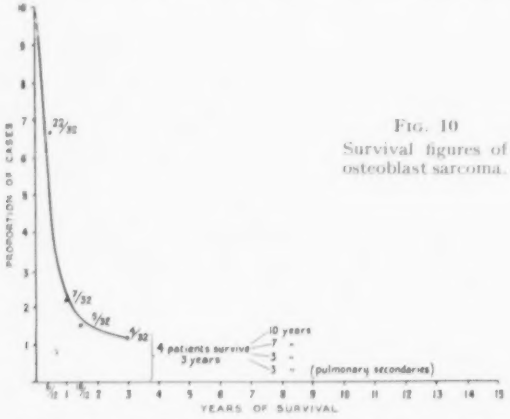

FIG. 10
Survival figures of osteoblast sarcoma.

mortem examinations were not performed, the details of the metastatic spread of many of the tumours are unknown. All the secondary deposits in lung, bone and kidney that we examined histologically showed an appearance identical to that of the primary tumour. There is no available specimen showing a deposit of this type of tumour in a lymph node in the present series.

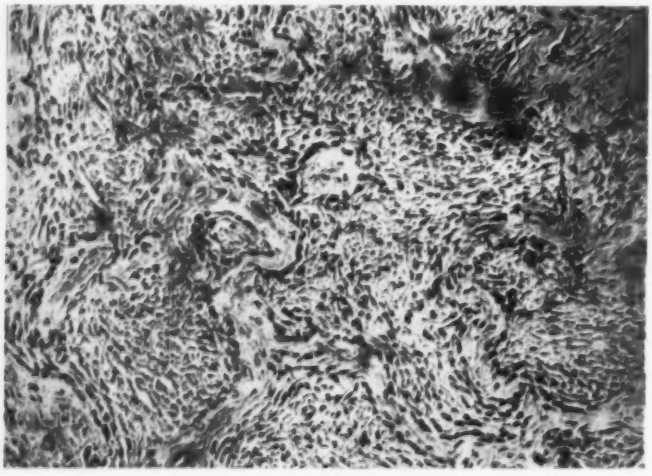

FIG. 11
A low power view of simple repair callus with its marked cellularity. (× 100.)

Only one tumour treated by amputation recurred in the stump. A tumour in the mandible treated by local excision and radium implantation recurred rapidly.

DISCUSSION

The sole criterion for the diagnosis of the osteoblast sarcoma is the histological picture. This tumour has usually been diagnosed in the past as an osteogenic (bone-forming) sarcoma.

Its malignancy has frequently been underestimated because less malignant bone-forming tumours have been included with it. The commonest of these is the ossifying chondrosarcoma. Whereas most histologists agree that ossification may occur in a chondrosarcoma, many still classify the extensively ossifying cartilaginous tumours with the osteoblast sarcomata and

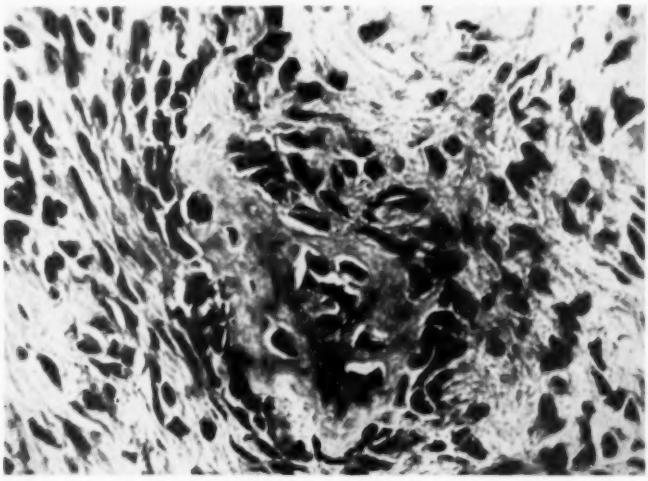

FIG. 12
An area of benign osteoblastic activity in simple repair callus. (×400.)

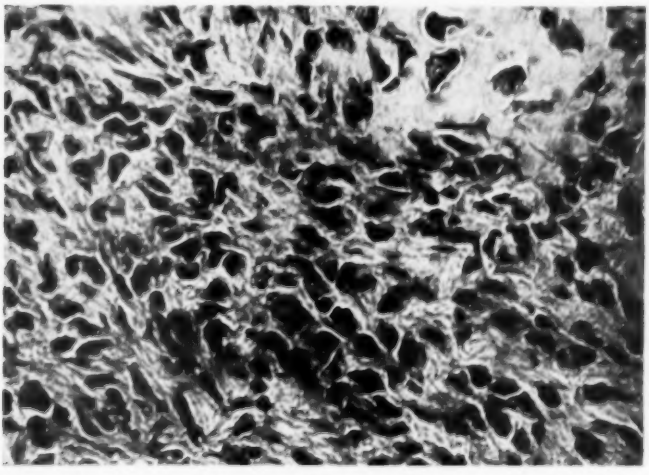

FIG. 13
The somewhat malignant appearance of the osteoblastic activity that may occur in simple callus. (×400.)

the ossifying fibrosarcomata, retaining the single heading osteogenic (bone-forming) sarcoma.

The presence of extensive areas of cartilage in a bone-forming tumour should raise the suspicion that the tumour is primarily a chondrosarcoma. Ossification in the matrix of some of these tumours can be very active, and the benign osteoblastic activity surrounding areas

of cartilage may give rise to diagnostic error; indeed if these osteoblastic areas are cut tangentially the cartilage in a given section may not even be a prominent feature.

This benign osteoblastic activity is particularly evident in ossifying chondrosarcomata that have been treated by irradiation. This is a pathological, but not a malignant, reaction to irradiation: the phenomenon is well known to the radiologist, who often sees a striking increase in the sclerosis of a treated tumour. In addition, the histological appearances of these tumours may be further complicated because the irradiation produces bizarre appearances in the benign osteoblasts. A tumour should not, therefore, be classified within this scheme from a post-irradiation biopsy or specimen.

FIG. 14

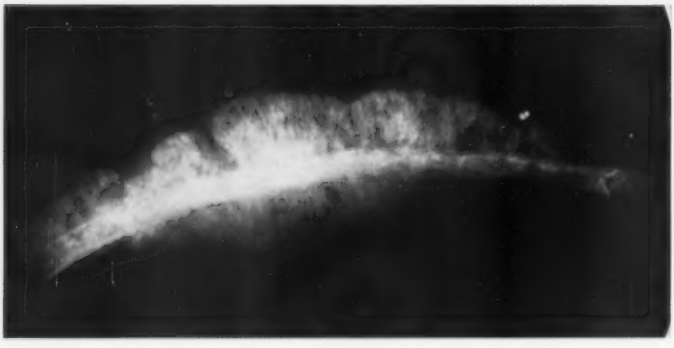

FIG. 15

Figure 14—The so-called " sun-ray spicules " in a tumour of the rib. This is the site of a secondary deposit of carcinoma from a primary in the colon.
Figure 15—Radiograph of the specimen.

The osteoblast sarcoma is considered to be the malignant counterpart of subperiosteal ossification and, as has already been mentioned, it is not always easy to differentiate from simple repair callus. This again may cause difficulty in histological diagnosis, for many tumours of bone, both primary and secondary, are surrounded by simple, benign subperiosteal bone formation (" sun-ray spicules " and Codman's triangle). Inadequate biopsy of a tumour may sample only this area of reactive new bone and lead to a false diagnosis of osteoblast sarcoma (Fig. 36).

The osteosarcoma is the most highly malignant of bone tumours, and only four patients in this series survived three years. This is a sinister outlook but, despite the small numbers,

we believe that this is a fair index of the behaviour of the tumour. Many published accounts of " osteogenic " (bone-forming) sarcoma with a five-year survival figure of 20 or 30 per cent must surely contain examples of the more benign bone-forming tumours (Fig. 64). If a critical analysis is made of this tumour, with histological examination as the only proof of identity, the prognosis of the osteoblast sarcoma will probably prove to be in the region of 10 per cent five-year survival.

In this series the histological grading of the tumour in relation to the degree of differentiation of the osteoblastic tumour cells, and the extent of bone formation, has proved of no value in assessing the prognosis.

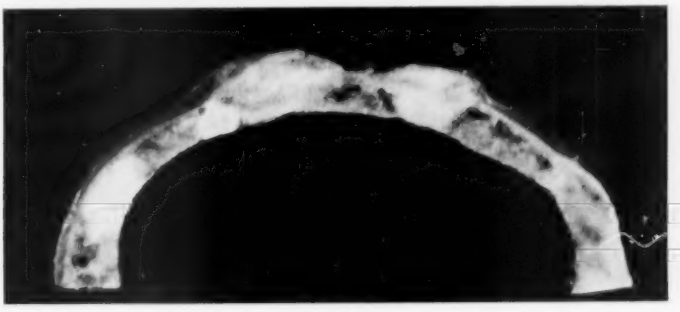

FIG. 16

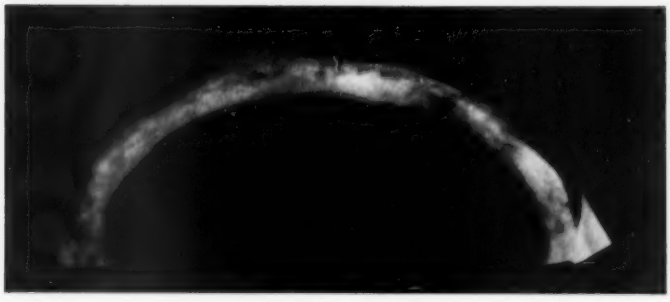

FIG. 17

Figure 16—Paget's disease of the skull with associated osteoblast sarcoma.
Figure 17—Radiograph of the specimen.

CHONDROSARCOMA

The diagnostic criterion of the chondrosarcoma is the presence of atypical cartilage which forms the predominant tissue. Many chondrosarcomata undergo ossification; when this is extensive the tumour is frequently classified under the heading of osteogenic (bone-forming) sarcoma.

There are sixty-eight examples of chondrosarcoma in this series; six were associated with Paget's disease.

Age—Chondrosarcoma occurs at all ages from ten to eighty, and is only slightly less common in the older age groups (Fig. 18). Of the seven tumours occurring over the age of sixty-five, six were associated with Paget's disease.

Sex—More than two-thirds of the cases occurred in male patients; there were forty-eight males and twenty females.

Sites—Table II shows the sites of origin of the sixty-eight tumours. The high incidence of pelvic primary sites may be in part accounted for by the number of patients referred to Sir Gordon Gordon-Taylor at this hospital with a view to hindquarter amputation.

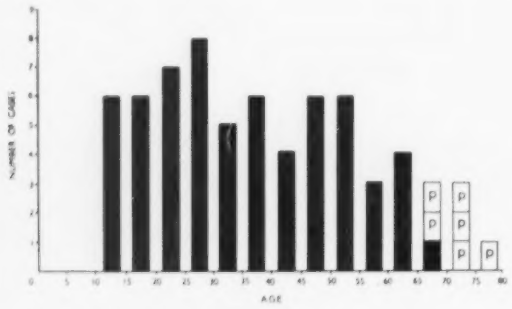

FIG. 18

Age incidence of chondrosarcoma. P = Tumour associated with Paget's disease.

Length of history—The average length of history before examination was thirteen months: the patient with the shortest history had a pathological fracture, and the one with the longest had had a palpable tumour for ten years.

Macroscopic appearance—The glistening, translucent and lobulated appearance of the cut surface of a chondrosarcoma is familiar and most can be readily diagnosed at a glance. There is great variation in size, and although a few may remain intramedullary at the time of operation, most tumours have eroded the cortex, with considerable bulging of the tumour mass into the soft tissues, the bulk of the tumour appearing outside the normal contour of the bone.

TABLE II

SITES OF CHONDROSARCOMA (SIXTY-EIGHT CASES)

Humerus		**Tibia or fibula**	
Upper end	6	Upper end	6
Middle	—	Middle	1
Lower end	—	Lower end	1
Pelvis	26	**Skull**	3
		Jaw	2
		Chest wall	3
Femur			
Upper end	10	**Finger**	1
Middle	2		
Lower end	6	**Scapula**	1

Many tumours show areas of calcification or ossification recognisable macroscopically. Some are so extensively ossified that the cartilaginous matrix is not visible to the naked eye. Others, especially the larger ones, show areas of degenerative softening of the cartilage with cyst formation.

FIG. 19

FIG. 20

Chondrosarcoma. Radiograph of the specimen (Fig. 20) shows extensive ossification of the tumour.

FIG. 21

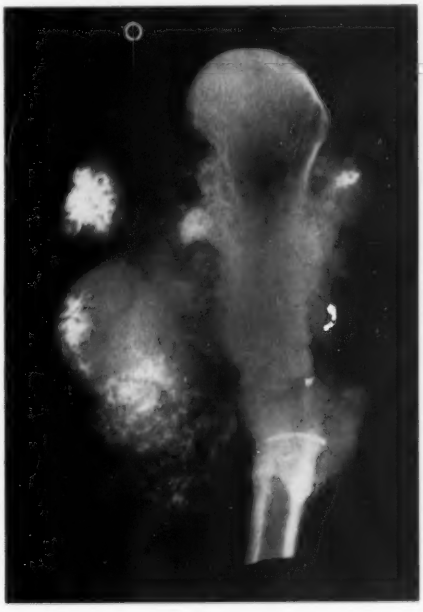

FIG. 22

Chondrosarcoma. Radiograph of the specimen (Fig. 22) shows patchy areas of calcification in the tumour.

Microscopic appearance—The diagnostic feature of the chondrosarcoma is the presence of atypical cartilage. These tumours fall into three histological grades which correspond to low, average and high degrees of malignancy.

The low-grade, well differentiated chondrosarcoma is similar in appearance to its benign counterpart, the chondroma, and, as stressed by Lichtenstein and Jaffe (1943), it can sometimes be differentiated only by careful histological scrutiny of the pathological material. The bulk of the tumour is composed of a cartilaginous matrix which is relatively acellular; the cells in these areas are regular and do not give the impression of malignancy. In other areas, especially at the periphery, there is an increased cellularity with a diminution in the proportion of the matrix. The cells in these regions are atypical, with variation in their size, and although mitotic figures are rare, many double nuclear forms may be visible in one

FIG. 23

FIG. 24

Chondrosarcoma. Showing a chondrosarcoma of the shaft of the fibula with little calcification or ossification visible in the radiograph of the specimen (Fig. 24).

microscopical field. In addition, at the growing edge, evidence of local infiltration can be seen. These are the histological appearances of the low-grade chondrosarcoma.

The cartilage in the average-grade tumour, although still readily recognisable, is more atypical in appearance. The matrix is reduced, with a proportionate increase in the cellularity; the cells vary both in size and shape, and show many abnormal nuclear forms.

The high-grade chondrosarcoma is comparatively rare. The appearances are those of a highly malignant sarcoma, with a poorly differentiated cartilaginous pattern. The greater part of the tumour is composed of pleomorphic anaplastic cells with grossly abnormal nuclear configuration and mitotic activity. In the less undifferentiated areas highly atypical, but recognisable, islands of cartilage are seen.

Tumours of all grades of malignancy may show additional features. As in benign chondromata, there may be areas of myxomatous degeneration or calcification of the stroma.

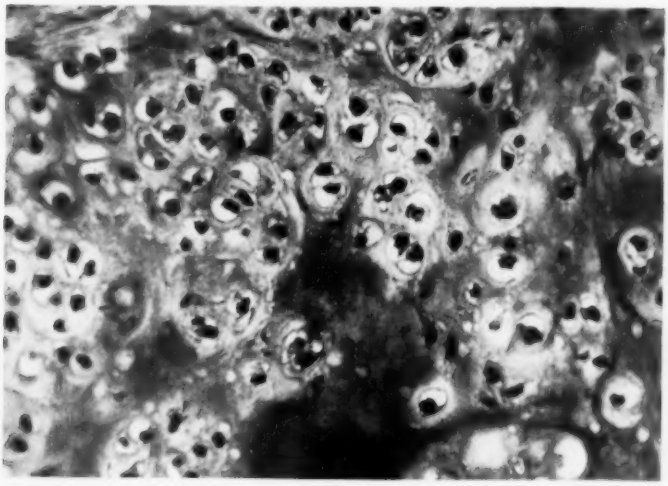

FIG. 25

The cellular appearance of a grade I chondrosarcoma. This section was taken from a secondary deposit in the lung. This patient was alive, but with multiple metastases, twelve years after initial treatment. (× 400.)

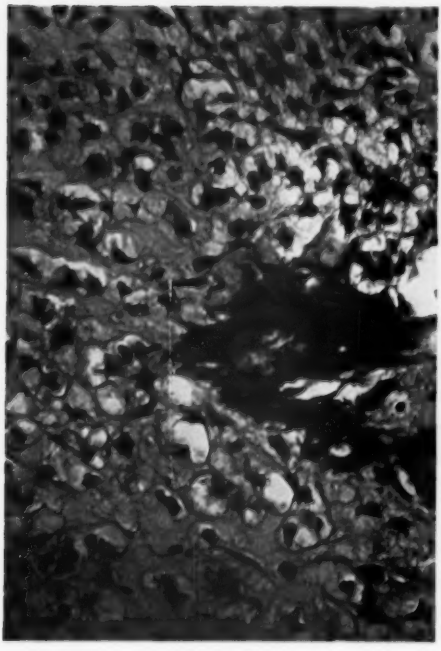

FIG. 26

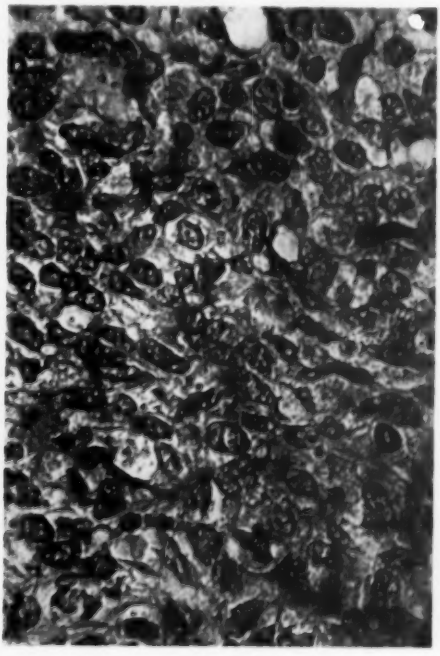

FIG. 27

Figure 26—The cellular appearance of a grade II chondrosarcoma. There is an area of calcification. The patient died with metastases four years after initial treatment. (× 400.) Figure 27—The cellular appearance of a chondrosarcoma of grade III malignancy. This patient died with metastases within a year of treatment. (× 400.)

These have no prognostic significance. Ossification of the matrix frequently occurs. Solid bony trabeculae replace areas of cartilage, and in the zones of active ossification a margin of normal osteoblastic activity may be found. Similar changes are seen in a benign osteochondroma, and are analogous to the physiological process of ossification of the epiphysial cartilage during normal bone growth.

Prognosis—It has become more widely recognised that the chondrosarcoma has a better prognosis than the other bone sarcomata. Figure 28 shows the survival figures in this series. It will be seen that there is approximately a 50 per cent five-year survival and a 40 per cent

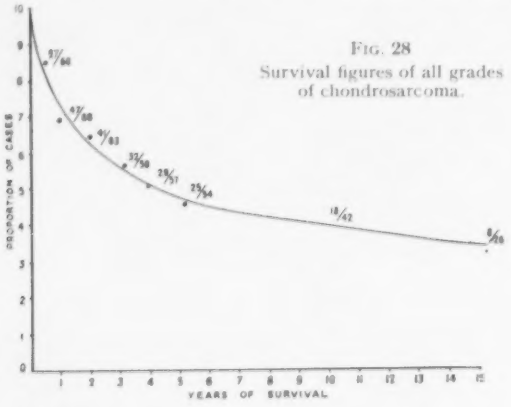

FIG. 28
Survival figures of all grades of chondrosarcoma.

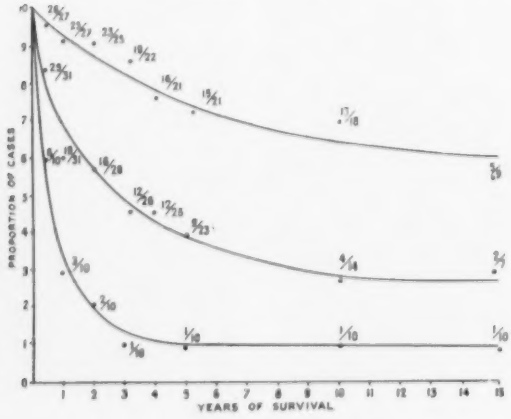

FIG. 29
Survival figures of the three histological grades of chondrosarcoma.

fifteen-year survival. These figures are clearly better than those for osteosarcoma and fibrosarcoma.

In this series there were twenty-seven cases of low-grade, thirty-one of average grade, and ten of high-grade malignancy as judged histologically. The survival figures have been analysed according to the different grades of malignancy (Fig. 29). It can be seen that tumours in these three grades behave differently. Nearly three-quarters of the patients with a low-grade tumour were alive ten years after treatment and more than a half at fifteen years. Of the average-grade cases less than half were alive at five years and only one-third at ten years. The high-grade chondrosarcoma behaves like the osteoblast sarcoma; only one of the ten patients survived three years.

Treatment. *Radical surgery*—Twenty-five patients were treated by radical surgery and of these, ten have died, eight with pulmonary metastases and two with local recurrences after amputation through the bone of origin (pelvis). Of these twenty-five tumours, nine were of low grade (one fatal), eleven were of average grade (five fatal), and five were of high grade

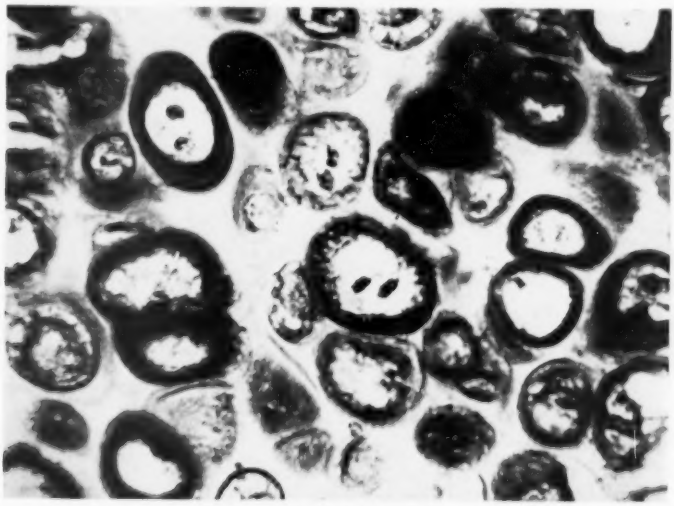

FIG. 30
Showing the double nuclear pattern visible in the cartilage cells of a grade II chondrosarcoma. (×400.)

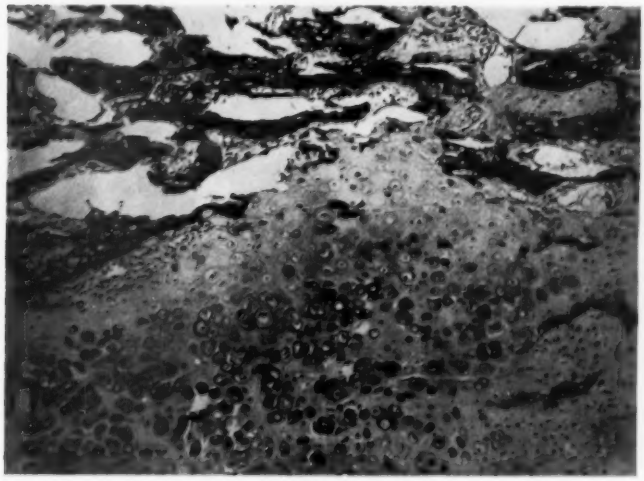

FIG. 31
An extensively ossifying chondrosarcoma. (×100.)

(four fatal). Fifteen patients are alive at the present time, but three of these were treated less than four years ago.

Local surgery—Of the eighteen patients (fifteen low-grade tumours, three average) treated initially by local excision, five are alive and well (four low-grade tumours, one average).

Thirteen tumours recurred locally (eleven low-grade, two average), but five of the patients are alive and well six years after additional surgery (three low-grade tumours, two average). The remaining eight patients (all with low-grade tumours) with local recurrences all died despite additional treatment (radiotherapy in two cases, radical surgery in three, local surgery in three).

FIG. 32

Areas of calcification and active ossification in a chondrosarcoma. (×400.)

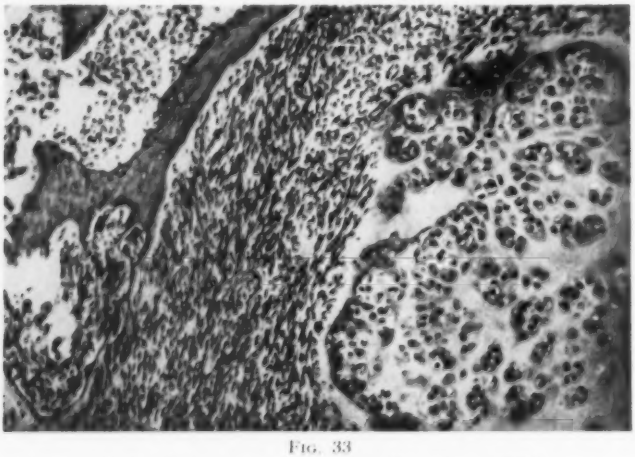

FIG. 33

A chondrosarcoma with spindle-cell areas. (×400.)

Thus of the eighteen patients originally treated by local excision ten are alive and well (seven low-grade tumours, three average).

Radiotherapy—Eleven patients were treated by radiotherapy alone (one low-grade tumour, seven average, three high). Seven patients died within a year of treatment, two in the third year and one in the sixth year; the patient with the low-grade tumour died in the tenth year.

Surgery and radiotherapy—Ten patients received combined irradiation and surgery as initial

treatment (three low-grade tumours, four average, three high). Four patients remain alive and well (two low-grade tumours, two average).

Four patients (all with tumours of average grade) died untreated.

Metastases—Of the thirty-eight patients who died at least seventeen are known to have had secondary deposits in the lungs, but, as many patients died outside hospital and did not have a post-mortem examination, this figure is almost certainly an underestimate. Other

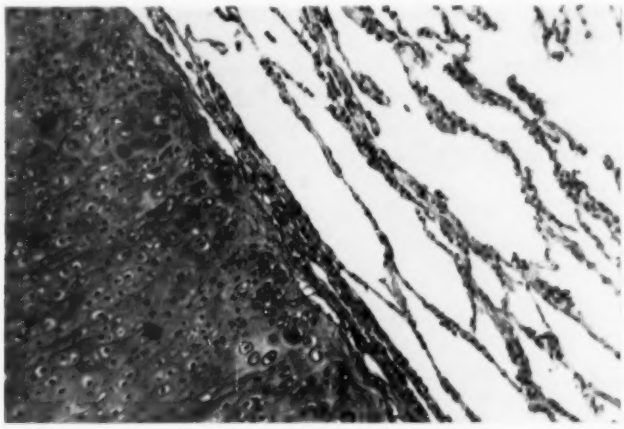

FIG. 34

A chondrosarcoma in lung (see Fig. 25). (× 100.)

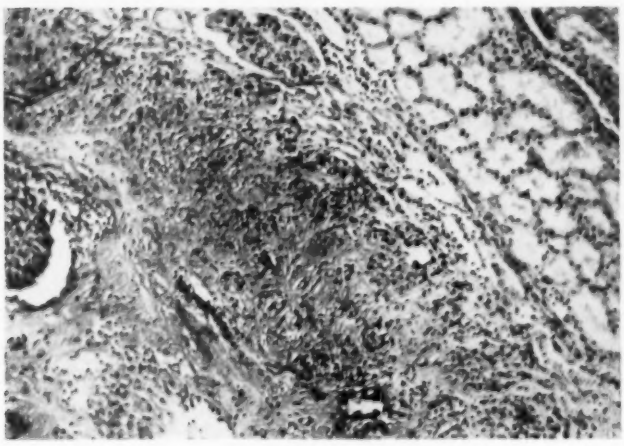

FIG. 35

A secondary deposit of chondrosarcoma in kidney. (× 100.)

secondary deposits have been found in distant bones, liver, kidney, pancreas and spinal dura. There is no available histological material in this series showing lymph node involvement. All the metastases that have been examined microscopically are similar in all respects to the primary tumour, indicating that a chondrosarcoma remains and metastasises as a chondrosarcoma.

DISCUSSION

As with the benign chondromata, the matrix of the chondrosarcoma often shows areas of myxomatous degeneration, calcification or ossification. These pathological changes are of

no prognostic significance, for the tumour appears to behave according to the histological grade of the chondrosarcomatous element.

The commonly used terms myxo-chondro-sarcoma, osteo-chondro-sarcoma and osteogenic (bone-forming) sarcoma are merely descriptions of irrelevant pathological appearances which neither aid the histological diagnosis nor serve as a guide to behaviour or prognosis.

The microscopic appearances of bone formation in cartilaginous tumours vary. In some areas calcification and bone formation are seen within the matrix of a cartilaginous island with no visible surrounding osteoblasts. In others active ossification is proceeding by simple, benign osteoblastic activity on the margin of the cartilaginous areas. This type of tumour is apt to be confused with the osteoblast sarcoma, especially in post-irradiation biopsies. In some particularly sclerosed examples of the ossifying chondrosarcoma areas of cartilage are largely replaced by bone, the structure of which tends to retain the basic cartilaginous pattern, thus indicating the true diagnosis.

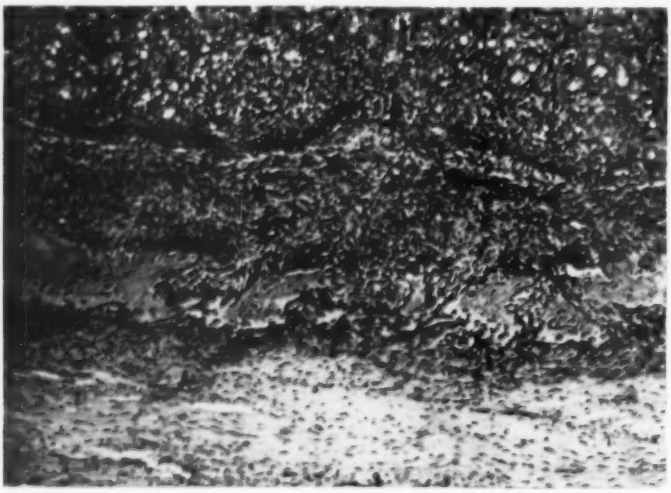

FIG. 36

A chondrosarcoma with reactive subperiosteal new bone formation. (× 100.)

The myxomatous appearance often visible in other types of chondrosarcoma is due entirely to a mucoid degeneration of the cartilaginous matrix which results in softening of the tumour substance and cyst formation. This appearance is not to be confused with the recently described chondromyxoid fibroma (Jaffe and Lichtenstein 1948), of which there are no examples in the present series.

The grading of the cartilaginous tumours according to their degree of histological differentiation appears to be of practical value. The low-grade tumours have no particular age incidence and behave less aggressively than those of other grades. Eleven of the twenty-seven patients died, six from local recurrence in surgically irremovable sites such as the sacrum and chest wall. Four patients died from pulmonary metastases, and one from sepsis soon after the operation.

Pulmonary metastases from low-grade tumours may not become apparent for many years after the initial treatment. In one patient a pulmonary deposit was found eight years after a forequarter amputation for the primary tumour in the humerus. The secondary deposit was removed from the left upper lobe of the lung by segmental excision, and the patient is still alive three years later, in spite of metastatic deposits elsewhere.

Although it was the low-grade chondrosarcoma that first drew attention to the better prognosis of the cartilaginous tumours, the average-grade examples also have a much less aggressive behaviour than the osteoblast sarcoma or the fibrosarcoma.

Of the thirty-one patients with average-grade tumours nineteen have died; at least eight of these had proven pulmonary metastases at the time of death, although in the absence of a terminal examination this figure is almost certainly too low.

At the malignant end of the scale the high-grade type of chondrosarcoma approximates in its behaviour to the osteoblast sarcoma.

FIBROSARCOMA

Fibrosarcoma of bone is a malignant tumour with one diagnostic feature, the formation of collagen by the tumour cells. Histologically it is identical with the more widely recognised fibrosarcoma of soft tissue.

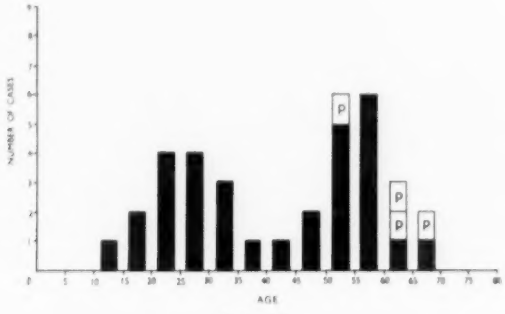

FIG. 37

Age incidence of fibrosarcoma. P—Tumour associated with Paget's disease.

There are thirty-four examples of this tumour in the series, four of which were associated with Paget's disease.

Age—The tumours of this series occurred at all ages, with peaks in the third and sixth decades (Fig. 37). Of the five cases occurring over the age of sixty, three were associated with Paget's disease.

Sex—Eighteen patients were male and sixteen female.

Sites—Two-thirds of the tumours occurred in long bones and half of these arose in the region of the knee joint (Table III). The two tumours arising in the skull were associated with Paget's disease. The tumours in the other cases of Paget's disease arose in the mid-shaft of the tibia and in the calcaneum.

Length of history—The average length of history before the patient attended hospital was seven months: the longest was thirty months. The patient with the shortest history had no symptoms until a pathological fracture occurred through the site of the tumour.

Macroscopic appearance—These tumours have been described as periosteal and medullary, according to their supposed site of origin. The distinction between a soft-tissue, a periosteal and a medullary fibrosarcoma is, however, a matter of anatomical site and extent, for microscopically they are indistinguishable. Most of the tumours in this series are of the medullary type. Soft-tissue tumours have been excluded and the remainder are examples of fibrosarcomata which have arisen in the periosteal region, but which show evidence of invasion

FIG. 38

FIG. 39

Fibrosarcoma. A central tumour in bone with no invasion of the soft tissues. Figure 39 is a radiograph of the specimen.

FIG. 40

FIG. 41

Fibrosarcoma. Showing a fibrosarcoma of bone with invasion of the adjacent soft tissues. The radiograph (Fig. 41) shows reactive periosteal new bone formation.

and characteristic destruction of the medullary cancellous bone at an early stage of the disease. Fibrosarcomata arising in the periosteal region, but not invading bone, have been excluded because they are more rationally considered among the soft-tissue growths.

Many examples of this tumour remain wholly intramedullary at the time of amputation. They show characteristic lengthwise spread in the cancellous bone with erosion and expansion, but not complete penetration, of the cortex. Other examples, although still showing this

TABLE III

SITES OF FIBROSARCOMA (THIRTY-FOUR CASES)

Femur		**Radius or Ulna**	
Upper end	1	Upper end	—
Middle	1	Middle	1
Lower end	8	Lower end	1
Tibia or Fibula		**Ilium**	2
Upper end	6	**Mandible**	2
Middle	1		
Lower end	2	**Skull**	2
Humerus		**Foot**	2
Upper end	2	**Rib**	2
Middle	—		
Lower end	—	**Scapula**	1

intramedullary type of extension, have penetrated the cortex to involve soft tissues, forming a tumour mass outside the bone.

The cut surface of a fibrosarcoma of bone differs in no essential from its counterpart in the soft tissues, except that, in the early stages of intramedullary invasion, fragments of cancellous bone may be palpable in the fibrous tumour.

Microscopic appearance—Microscopically the relatively well differentiated examples show fibroblastic tumour cells with extensive collagen formation. The more cellular varieties exhibit greater pleomorphism, often with multinucleate forms and less collagen. The matrix of any fibrosarcoma may undergo mucoid degeneration and small areas of calcification may also occur. These changes are comparable to those seen in the stroma of a chondrosarcoma.

Since the tumour spreads by infiltration of cancellous bone, surviving bony trabeculae are visible, particularly at the margin of the tumour. In addition small areas of new bone formation are occasionally seen in which the collagen is replaced by osteoid tissue as a result of simple osteoblastic activity. This ossification is regular and appears comparable to the physiological process of "ossification in membrane." It is merely another example of bone formation in a tumour matrix; neither the cellular pattern nor the prognosis resembles that of the osteoblast sarcoma.

Treatment. *Radical surgery*—Fifteen patients were treated by radical surgery: eight died within three years of diagnosis and six are alive. Two of the survivors have lived for two years, two for three years, one for four years and one for fourteen years after treatment. One patient died of natural causes in the seventh year with no evidence of recurrent tumour.

Local surgery—The one patient treated by local excision has survived two years.

Radiotherapy—Ten patients were treated by radiotherapy alone (palliative in at least two instances); all died within three years.

Surgery and radiotherapy—Three tumours were treated by local surgery and irradiation as a combined treatment; all three patients remain alive and well, eight, ten and fourteen years later.

Three tumours were treated by radical surgery and irradiation as an initial treatment.

One patient died at one year, another was killed in an accident during the second year, and the remaining patient is alive at three years.

Two further patients died untreated.

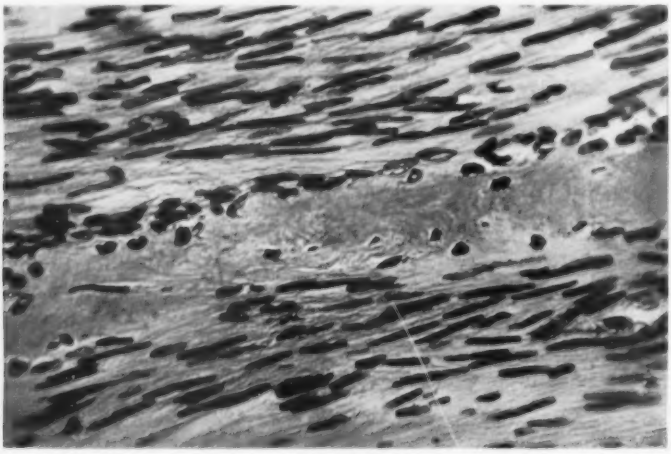

FIG. 42

A fibrosarcoma of low-grade malignancy. (×400.)

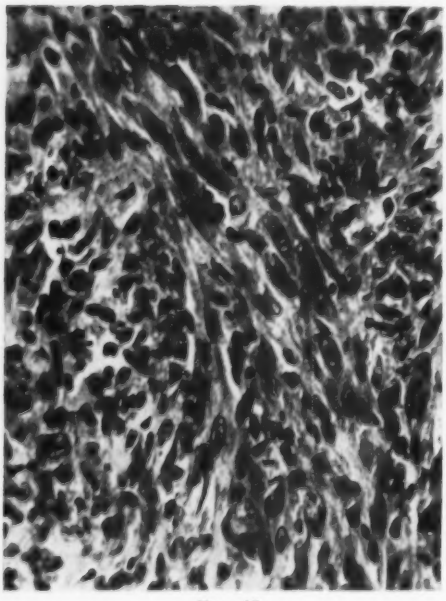

FIG. 43

A fibrosarcoma of average-grade malignancy. (×400.)

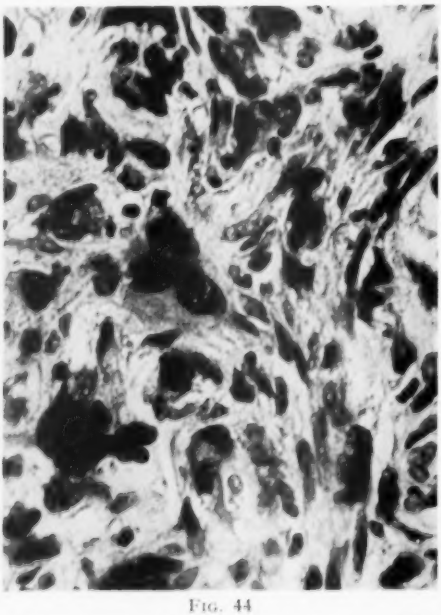

FIG. 44

A fibrosarcoma of high-grade malignancy. (×400.)

Prognosis—The survival figures for fibrosarcoma are summarised in Figure 46. Half of the patients died within two years of diagnosis, and three-quarters within five years. Of the five patients who have so far survived five years, two were treated by radical surgery, and the remaining three tumours were locally excised and irradiated. One tumour, treated in

this manner, recurred locally six years after treatment, and amputation was performed; histology showed active fibrosarcoma in the bone, but the patient remains well two years later.

Metastases—At least eleven of the twenty-one patients who died are known to have had secondary deposits in the lung, and in four cases there was histological evidence of lymph

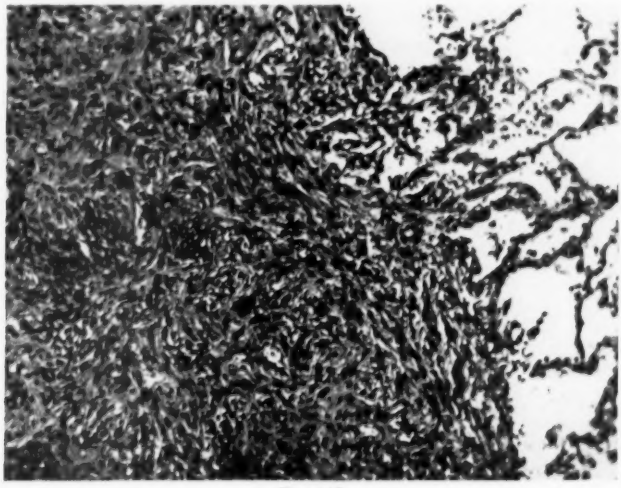

FIG. 45

A secondary fibrosarcoma of bone in the lung. (× 100.)

node metastases. Three patients died from bony secondaries in the spine. Five tumours recurred locally, three after irradiation, and two in the stump after subtrochanteric amputation for tumours at the lower end of the femur.

All secondary deposits that we have examined histologically have been identical in appearance to the primary tumour.

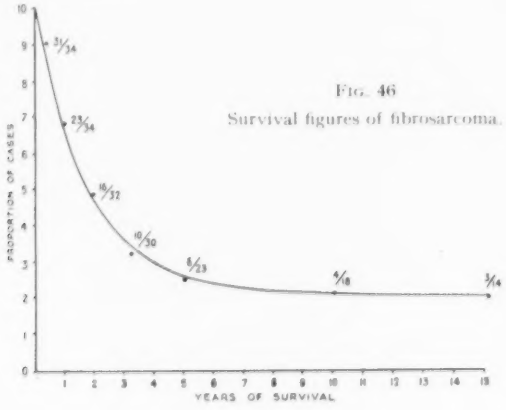

FIG. 46

Survival figures of fibrosarcoma.

DISCUSSION

Some authorities doubt the existence of the fibrosarcoma of bone as a separate entity. Thus Geschickter (1932) regarded all these tumours found in bone as arising in adjacent soft tissues, with subsequent bony invasion. He regarded fibroblastic tumours in the medullary cavity but with no extension into soft tissues as undifferentiated examples of "osteogenic" or chondrosarcoma with no characteristic matrix production.

Scarff (1937) included fibrosarcoma of the bone in his classification of bone tumours, and many subsequent authors have agreed (Macdonald and Budd 1943, Phemister 1948, Coley 1949, and Lichtenstein 1952). Macdonald and Budd (1943) recognised fibrosarcoma as a specific entity occurring in bone, and found that 31 per cent of the five-year survivors of "osteogenic" (arising from bone) sarcoma registered with the Bone Tumour Registry were in fact examples of this type.

The fibrosarcomata have a diagnostic microscopic appearance and the general prognosis, as judged from this present series, lies between that of the highly malignant osteoblast sarcoma and the chondrosarcoma group. This is not in agreement with the findings of Macdonald and Budd (1943), but they included the spindle-cell sarcoma in their series.

An attempt was made to grade the fibrosarcomata according to their degree of collagenous differentiation and cellular appearance. Of the thirty-four tumours only two were well differentiated (grade I), twenty were of average malignancy (grade II) and twelve of high-grade malignancy (grade III).

The histological distinction between fibrosarcomata of grades II and III was less readily definable than in the chondrosarcoma and giant-cell series because of the diversity of the histological pictures encountered.

The tumours of grades II and III in this series all behaved poorly, so the distinction between them has little practical value. The uncommon grade I tumours appear less aggressive, for both patients are among the survivors at the present time.

SPINDLE-CELL SARCOMA

The tumours of this group are highly cellular neoplasms composed of undifferentiated spindle cells. The relative absence of intercellular tissue is the striking feature. There are only eleven examples in the series.

Age—The ages were thirteen, fourteen, eighteen, eighteen, nineteen, twenty, twenty-one, twenty-five, thirty-two and fifty-two (age unknown in one case).

Sex—There were six males and five females.

Sites—The tumours arose in the foot, radius, clavicle, upper and lower femur and the upper end of the fibula; five arose from the pelvic bones.

Macroscopic appearance—The tumours are soft and haemorrhagic, with expansion and destruction of the bone of origin and in some cases invasion through the periosteum to involve the adjacent soft tissues.

Microscopic appearance—Histologically the tumour is composed of masses of spindle cells of uniform appearance: pleomorphic areas, mitotic activity and giant-cell forms are unusual. Most of the tumour is composed of these spindle cells with a negligible intercellular tissue. The absence of matrix is a striking feature of this tumour, and it indicates a complete absence of histological differentiation.

Treatment—Four patients had radical surgery alone; three died within six months from pulmonary metastases and one remains alive and well four years later.

Three patients were treated by radiotherapy alone; two died within six months, and one remains alive and well six years later.

Four patients had a local resection of the tumour as the initial treatment; the tumour recurred in all and was then treated by irradiation. One patient died with pulmonary secondaries five years later; the other three, treated by additional radical surgery, remain alive five, seven and fifteen years later.

Prognosis—Five of the patients died within the first six months after treatment and one after five years. Five remain alive four, five, six, seven, and fifteen years later.

Metastases—Four patients were known to have pulmonary metastases at the time of death, and a further patient had multiple bone secondaries.

DISCUSSION

This small group of tumours has an interesting histological picture and clinical course.

The spindle-cell sarcoma of bone, like the similar tumour of soft tissue, is a histologically descriptive title which does not imply a specific histogenetic entity. It is merely a group of tumours showing a characteristic cellular appearance with a marked absence of matrix. It may be that they are an undifferentiated form of fibrosarcoma with no collagen formation;

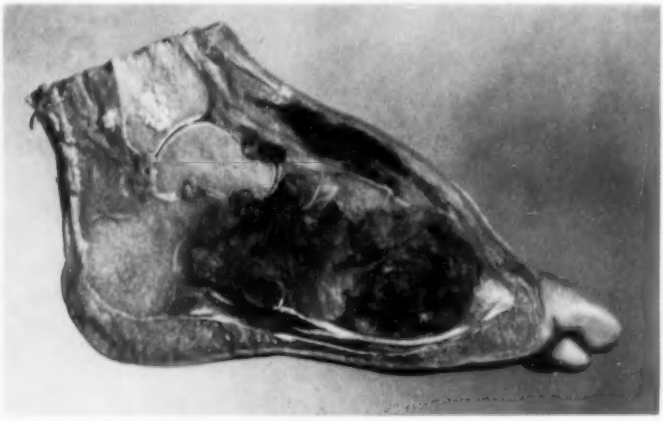

FIG. 47

FIG. 48

Figure 47—Spindle-cell sarcoma. A tumour involving the bones of the foot. Figure 48 is a radiograph of the specimen.

they are often regarded as such. They present, however, quite a different appearance from the poorly differentiated fibrosarcoma; for the latter, in addition to areas of collagenous intercellular matrix, also shows a marked degree of pleomorphism with bizarre nuclear pattern and tumour giant cells. Compared with these, the uniform pattern of the spindle-cell sarcoma does not convey the same impression of malignancy, for both the cells and the nuclei are almost invariably regular, and mitotic activity is not a prominent feature.

For these reasons it seems logical to compare and contrast the behaviour of the spindle-cell sarcoma and the fibrosarcoma critically before accepting their coalition. Since there are only eleven cases in this series the details of behaviour must be accepted with reserve. In four of the five fatal cases the patient died within six months of treatment; those that survived this period have lived for five years or more, with the exception of one who is still alive and

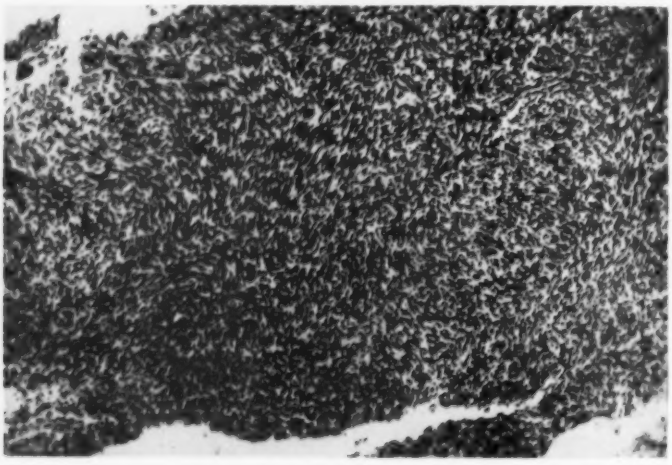

FIG. 49
Showing the cellularity of a spindle-cell sarcoma. (×100.)

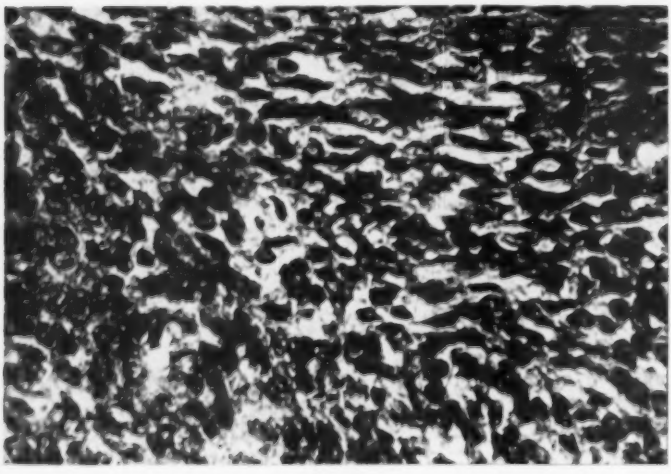

FIG. 50
Spindle-cell sarcoma of bone. Patient alive seven years after initial treatment. (×400.)

well at four years. One of these patients subsequently died at five and a half years, and another, although still alive, has pulmonary metastases in the seventh year after treatment.

There is a tendency for the spindle-cell sarcoma to occur at a younger age than the fibrosarcoma. Nine of the eleven tumours arose in patients between the ages of thirteen and twenty-five. There is also some evidence that the spindle-cell sarcoma is more radiosensitive.

It may be that a larger number of cases of this tumour type will show that there is little to be gained by their separation and that a single histological diagnosis of fibro-spindle-cell sarcoma will convey all that is of practical value. In the meantime, however, we prefer to retain the individual diagnoses of fibrosarcoma and spindle-cell sarcoma until the clinical value of this histological distinction can be accurately assessed.

GIANT-CELL TUMOURS

The histological feature of this group of tumours is the cellular stroma in which there are many giant cells of the osteoclast type. In the past these tumours have often been regarded as benign. This is far from the truth, for in this series of thirty-four tumours half recurred locally after treatment and a quarter of the patients died with metastases.

Age—The age incidence is shown in Figure 51. Most of the cases fall in the twenty to forty age group. Two tumours occurred in patients of sixteen but none below the age of fifteen. Three patients were over the age of sixty, two of whom were known to have Paget's disease.

Sex—There was an equal sex distribution with seventeen males and seventeen females.

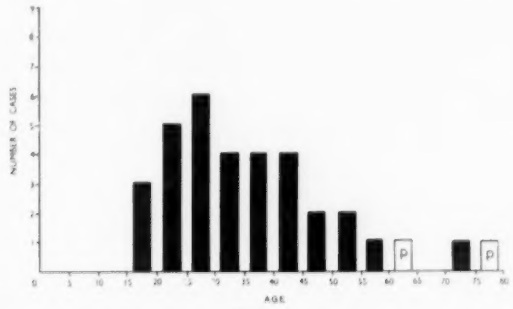

FIG. 51

Age incidence of giant-cell tumours. P = tumour associated with Paget's disease.

Sites—More than three-quarters arose at the ends of long bones and three-quarters of these occurred in the region of the knee (Table IV). There are no examples of this tumour arising from the middle third of a long bone.

Length of history—The average duration of symptoms was seven months, varying from one month to three years, with the exception of two cases in which the patient presented with a pathological fracture.

Macroscopic appearance—As with the chondrosarcoma, the macroscopic appearance of the giant-cell tumour is well recognised and can frequently, but not infallibly, be diagnosed from the cut surface of the specimen or from the radiograph.

The bone is expanded by a red, fleshy, haemorrhagic tumour which replaces the medulla and markedly thins the expanding cortical bone. It commonly extends up to the articular cartilage, but the joint is spared, and the periosteum remains intact except in the more aggressive examples.

Microscopic appearance—The histological features of this tumour are a vascular cellular stroma in which there are many giant cells of the osteoclast type. The stromal cells are of two varieties: spindle cells are found which have elongated darkly staining nuclei and little cytoplasm, but the predominant cell has a plump pink-staining cytoplasm containing an oval or round vesicular nucleus. The giant cells, which form so prominent a feature, are uniform with an abundance of sharply defined pink-staining cytoplasm containing upwards

FIG. 52

FIG. 53

Giant-cell tumour. The appearance of a histologically grade I giant-cell tumour. Figure 53 is a radiograph of the specimen.

FIG. 54

FIG. 55

Giant-cell tumour. The appearance of a histologically grade II giant-cell tumour. Figure 55 is a radiograph of the specimen.

of fifty nuclei with a central aggregation. These nuclei are vesicular and closely resemble the predominant stromal cells in appearance; it seems likely that the giant cells have their origin from these.

The arresting feature of this tumour is the presence of the many giant cells, from which it derives its non-committal name. Some prefer the title of osteoclastoma because of the close

TABLE IV

SITES OF GIANT-CELL TUMOURS (THIRTY-FOUR CASES)

Humerus		**Patella**	1
Upper end	3		
Middle	—		
Lower end	1	**Vertebra**	1
Femur			
Upper end	2	**Pelvis**	2
Middle	—		
Lower end	10		
Tibia and Fibula		**Scapula**	1
Upper end	10		
Middle	—		
Lower end	2	**Jaw**	1

similarity of these giant cells to the osteoclast (Willis 1949). Unfortunately from the prognostic aspect it is not the giant cells that form the important element, but rather the stromal cells (Jaffe *et al.* 1940). These authors suggest that the subsequent behaviour of any giant-cell

FIG. 56

FIG. 57

Giant-cell tumour. The appearance of a histologically grade III giant-cell tumour. Figure 57 is a radiograph of the specimen.

tumour can be assessed by the cytological features exhibited by the stromal cells. They divide these tumours into three grades, I, II, and III. The grade I tumours display a stromal pattern of uniform cells and giant cells of regular appearance. There is little mitotic activity and the whole picture is that of a slowly growing tumour. This grade forms about a third (eleven cases) of this series and has a low recurrence rate after local treatment.

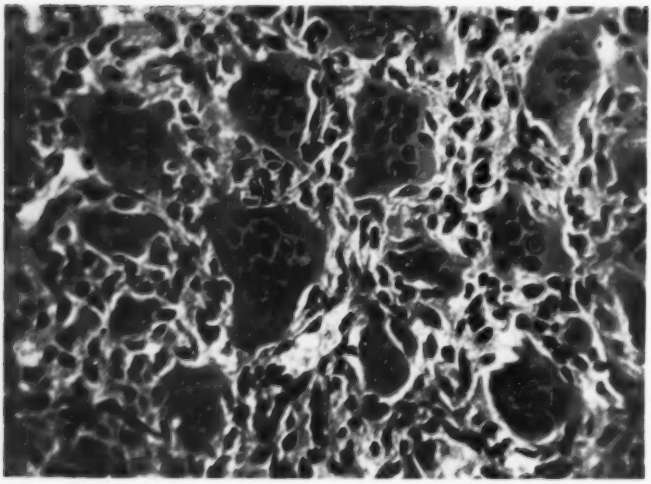

FIG. 58
Showing the regularity of both the stromal and giant cells of a grade I giant-cell tumour. (×400.)

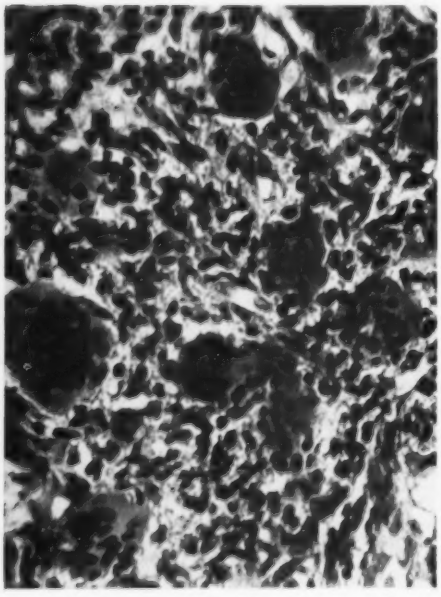

FIG. 59

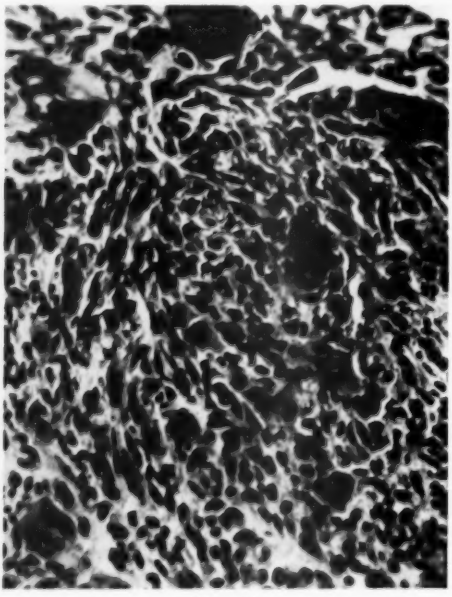

FIG. 60

Figure 59—Some irregularity of the stromal cells of a grade II giant-cell tumour. (×400.) Figure 60—Showing the irregularity of the stromal cells and the giant cells of a grade III giant-cell tumour. (×400.)

The grade II tumours show distinct cytological differences from those of grade I. There is increased cellularity of the stroma and the cells are irregular in shape, size and staining; mitotic activity is readily visible and the picture is one of a much more active tumour. The sixteen grade II tumours (nearly half the total) displayed more aggressive characteristics with a high incidence of recurrence.

The grade III tumours are those with a sarcomatous stroma. The cellular stroma is more pleomorphic, frankly mitotic activity becomes a prominent feature, and the diagnostic giant cells are irregular both in size and shape due to clumping of the stromal cells. These tumours are sarcomatous in behaviour; the seven in this series all invaded the soft tissues and four patients died with blood-borne metastases.

These three grades are very similar to the second, third and fourth grades suggested by the American College of Surgeons (Ewing 1939); their grade I tumours will be referred to here as giant-cell variants, for they are not true giant-cell tumours.

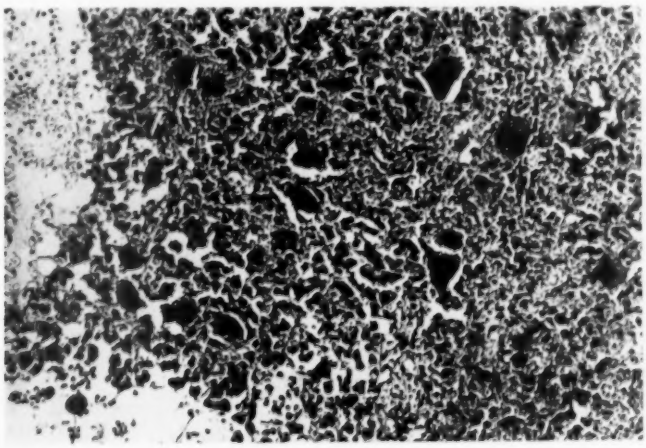

FIG. 61
A giant-cell tumour metastasis in lung. (×100.)

Prognosis—In the past the giant-cell tumours have usually been regarded as benign lesions, a small proportion of which gave rise to local recurrence, and rarely metastasised. In this series of thirty-four giant-cell tumours, eighteen recurred after local surgical and radiotherapeutic treatment, and eight patients died from distant metastases. In the course of treatment, sixteen patients have had amputations after the failure of more conservative treatment.

The survival figures are shown in Figure 62. This shows a five-year survival rate of approximately two-thirds. Figure 63 shows the mortality in the three histological grades of the tumour. To summarise briefly: five of the eleven patients with a grade I tumour developed local recurrences; all these responded to further treatment, although one patient died from natural causes. Of sixteen grade II tumours eleven recurred, and four patients died with metastases. Two further patients died, one from extension of the tumour in the sacral region, and the other from pulmonary embolism after an amputation for recurrence. Of the seven grade III tumours, two were associated with Paget's disease. Four died with pulmonary metastases and three remain alive and well three, six and twenty-six years after pre-operative irradiation and amputation.

It will be noted that all the fatal cases died before the end of the fifth year after treatment,

and no patient died during the first year. The only death among the patients with a grade I tumour was due to natural causes.

Treatment. *Radical surgery*—Four patients were treated by radical surgery alone. One had a resection of the patella (grade II tumour), another had an amputation of the leg (grade I tumour); both these patients remain alive and well. Two further patients died with pulmonary metastases after amputations (grade II and grade III tumours).

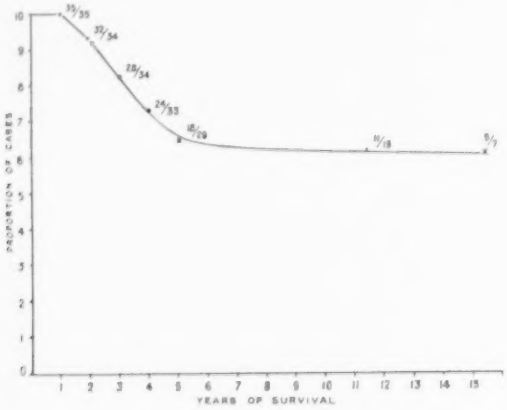

FIG. 62

Survival figures of giant-cell tumours.

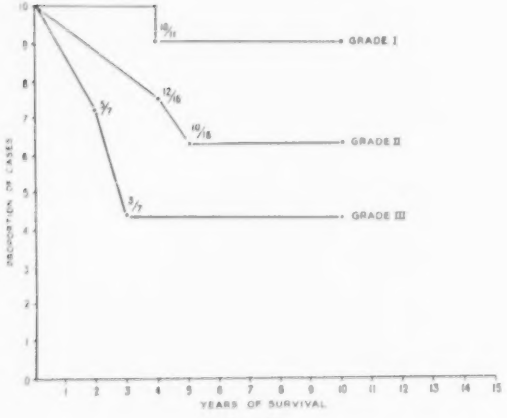

FIG. 63

Survival figures of the three histological grades of giant-cell tumour.

Local surgery—One tumour was treated by local resection of a tumour in the fibula. This recurred in the tibia and further extension after irradiation necessitated amputation; the patient is well seven years after the initial treatment (grade II tumour).

Curettage—Eleven tumours (three of grade I, seven of grade II, and one of grade III) were treated initially by curettage; only one curettage was successful and this was combined with local carbolic acid cauterisation at the time of operation (grade II tumour). Ten tumours recurred locally and were treated by radiotherapy; five of these were successfully controlled (three grade II tumours and two of grade I). Four patients died from pulmonary metastases

after further radical surgery (three grade II tumours and one of grade III), and only one patient (with grade I tumour) remains alive after amputation.

Thus of the eleven patients originally treated by curettage, only seven are alive in spite of energetic treatment of the recurrences.

Radiotherapy—Fifteen patients were treated by irradiation, with no previous surgery other than the initial biopsy. Of these, six are alive and free from recurrence (five grade I tumours and one of grade II).

Nine tumours were not controlled by irradiation (six of grade II and three of grade III). Four were later removed by amputation and the patients remain alive two to five years after diagnosis (three grade II tumours and one of grade III). The remaining five patients with recurrent tumours died, three from pulmonary metastases (one grade II tumour, two grade III tumours), and two died at the age of forty with active tumour. One (grade II) was extending into the sacrum; the other (grade I) was in the femur and the certified cause of death was chronic bronchitis and emphysema.

Of the fifteen patients originally treated by radiotherapy, ten remain alive and well but four of these required subsequent amputation for recurrence. Five of the six tumours that were controlled by irradiation were histologically in grade I.

Surgery and radiotherapy—Three tumours were treated initially by a combination of surgery and radiotherapy. One patient (grade II tumour) had irradiation immediately after local excision, and two (grade II tumours) had pre-operative irradiation; these three patients are alive three, twelve and eighteen years after treatment.

In short, twenty of the thirty-four tumours in this series recurred after treatment—eighteen locally, eight after curettage, nine after irradiation and one after local excision. Two showed pulmonary recurrence only, after radical excision of the primary.

Metastases—Eight tumours showed evidence of blood-borne metastases at the time of death (four of grade II, four of grade III), seven of which were in the lung. All the secondary deposits that we have examined histologically resembled the primary tumour.

DISCUSSION

The giant-cell tumour, because of its histological picture, has many imitators. As stressed by Jaffe *et al.* (1940) these include simple bone cysts, fibromata, fibrous dysplasia, lipoid dystrophy, fibro-xanthomata, and giant-cell epulis, all of which may contain many giant cells of the osteoclast type in a cellular stroma. Moreover, areas of osteoclastic bone absorption are frequently seen at the periphery of any bone lesion. Inadequate biopsy, sampling only this area, is an insufficiently appreciated cause of error in histological diagnosis.

Originally this series contained many more cases, but on closer scrutiny of the histological material, many were found to be examples of the above mentioned "giant-cell variants." Most of these occurred in the first and second decades, and in the present series there are only three examples of the giant-cell tumour occurring under the age of twenty.

After the exclusion of these histological imitators, nearly all of which have an excellent prognosis, a group of specific giant-cell tumours remains. These form a formidable series with a high recurrence rate after local treatment.

The diagnosis can be made only after careful histological study, and the prevalent tendency to apply this histological label to a clinical or radiological impression of a lesion is both unscientific and inaccurate. The aggressive character of the true giant-cell tumour has been underestimated in many of the reported surveys owing to uncritical or even absent histological examination.

Once the diagnosis has been confirmed histologically, and the tumour graded, its treatment should not be undertaken lightly. In this series of thirty-four tumours no less than eighteen recurred locally, and eight patients died from distant metastases. It seems,

therefore, more realistic and logical to regard the giant-cell tumour as a locally malignant neoplasm, a significant proportion of which may cause fatal metastases.

It seems from the relatively small number of cases in this series that grading does give some guide to the prognosis of a given tumour. The grade I tumours may recur locally, but have not metastasised. The grade II tumours are likely to recur locally and may metastasise: the metastasising examples of this grade cannot be differentiated histologically and the microscopic appearance of the secondary deposits is identical to those of the primary tumour. The grade III tumours behave as frank sarcomata and, unless early and radical treatment is instituted, metastases inevitably occur.

DISCUSSION

The main purpose of this work is to subdivide malignant tumours of bone into histological groups and to reassess the prognostic value obtainable from this method of classification. The subdivisions are based solely on specific cellular appearances without recourse to the naked eye, radiological or clinical appearances of the tumour. This seems to be the most logical and valuable method of classification. It differs from most of its predecessors in the interpretation of the significance of bone formation within the tumour. In our view the formation of osteoid tissue directly by malignant osteoblastic tumour cells is the only type of bone formation of prognostic significance. Simple ossification of the stroma of a tumour neither alters the basic diagnosis nor materially affects the prognosis.

Most of the 180 tumours in this series can readily be placed in one of the four main groups, as the tumour cells produce a diagnostic amount of osteoid tissue, cartilage, collagen or giant cells of the osteoclast type. There are, however, eleven tumours in this series which lack this diagnostic differentiation in the stroma. These form the fifth group, the spindle-cell sarcoma.

The main difficulty with a histological method of classification is the occasional tumour which shows a mixture of malignant tissues. The few examples of this in the present series have all been predominantly cartilaginous tumours with additional areas of spindle-cell, fibrosarcomatous or osteoblastic tissue. These appearances are exceptional and, although they may represent examples of a mixed type of tumour, for practical purposes this cellular picture is taken to indicate a higher grade of malignancy than the pure cartilaginous areas would suggest, approximating to the prognosis of the additional tumour type.

Furthermore, as previously described, a narrow margin of simple osteoblastic activity is commonly seen surrounding an ossifying chondrosarcomatous matrix. Very occasionally this osteoid tissue may form a prominent feature and assume the malignant cellular pattern of the osteoblast sarcoma, with extensive areas of malignant tumour bone formation and no intermediate matrix of cartilage. These tumours are considered to have the prognosis of an osteoblast sarcoma since in areas they are histologically indistinguishable.

The occurrence of these relatively infrequent mixed tumours containing more than one type of malignant tissue is no valid reason for grouping all osteoblastic, cartilaginous, collagenous and spindle-cell sarcomata together, for the great majority can readily be segregated, and their distinction appears to be reflected in the behaviour of the individual groups.

A bone tumour metastasises true to its cellular type; thus a chondrosarcoma metastasises as a chondrosarcoma. In the mixed type of tumour the histological appearance of the metastases, and the prognosis, are usually that of the most malignant type present.

The only accurate method of establishing the exact diagnosis of a bone tumour is by histological examination of the tumour tissue. Although this tissue may be obtained from an amputated specimen it is essential to examine biopsy specimens before a tumour receives radiotherapy, for the histological picture may be radically altered by irradiation and the precise nature of the original tumour may ever remain in doubt.

Apart from the disputed risks of dissemination of the tumour cells by biopsy, there are certain diagnostic hazards associated with it. It is desirable that the tissues submitted should be adequate and representative of the tumour, and for these reasons an open biopsy is preferred to a drill biopsy. An inadequate biopsy specimen may be most misleading. If it samples only the edge of a tumour surrounded by reactive periosteal new bone, a false diagnosis of osteoblast sarcoma may result; conversely, an area of eroded bone with prominent osteoclastic activity may simulate a giant-cell tumour. Adequate biopsy with sufficient tissue from a representative area will permit accurate diagnosis in most cases and will form a reliable basis for the assessment of further treatment.

Injury has often been regarded as a predisposing factor in the causation of " osteogenic " (bone-forming) sarcoma. This seems to have its foundation on two points: firstly, aching pain and local swelling, both common presenting symptoms of bone tumours, are frequently ascribed by the patient to previous and often trivial injury in that region; secondly, the exuberant callus that accompanies some examples of bone repair may be histologically difficult to differentiate from an osteoblast sarcoma. A history of injury was recorded in about half the cases in this series.

It is extremely doubtful whether injury does more than draw attention to an already existing bone lesion and there seems little real evidence to substantiate it as an etiological factor. Many thousands of fractures have been treated at this hospital since 1925 but so far as is known not one has subsequently developed a primary bone sarcoma at the site of injury. Since major trauma of bone does not seem to cause neoplasia it seems unreasonable to suppose that minor trauma, often involving soft tissues only, can be responsible.

In this series seventeen bone tumours were associated with Paget's disease. These included examples of each of the four main types of tumour—five osteosarcomata, six chondrosarcomata, four fibrosarcomata, and two giant-cell tumours. With the exception of the giant-cell tumours, the prognosis of the tumours associated with Paget's disease is uniformly poor, irrespective of the type of sarcoma present, for all the patients died within nine months of diagnosis. One of the patients with a giant-cell tumour died three years after diagnosis, but the other is alive five years later.

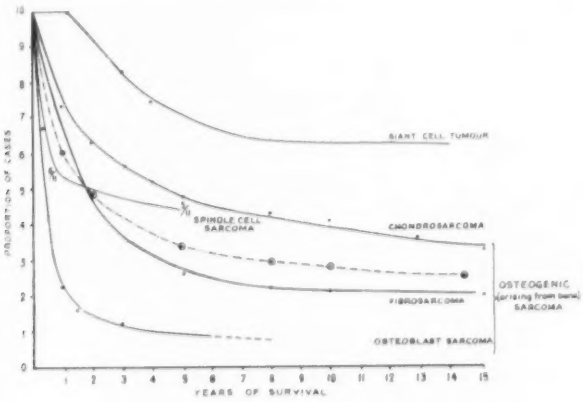

FIG. 64

Comparison of the survival figures of the histological types of malignant bone tumours.

The application of a rational histological classification, based solely on cellular appearances, to the present series of bone tumours is strikingly reflected in the behaviour of the individual tumour groups. As will be seen from Figure 64, if all the bone sarcomata are considered together much information of prognostic importance is lost; thus it takes fifteen years for

three-quarters of the "osteogenic" (arising from bone) sarcomata to cause death, but the osteoblast sarcoma achieves this dismal figure in a year. The further histological subdivision of the chondrosarcomata and giant-cell tumours according to their histological grade of malignancy gives an additional guide to the behaviour of these tumours.

We feel that the details of the bone tumours in this series will endorse the practical value of a histological classification of bone sarcomata and that the amalgamation of all types under the collective heading of "osteogenic" sarcoma is ambiguous, pathologically inaccurate, and prognostically valueless.

SUMMARY

1. One hundred and seventy-nine cases of primary malignant bone tumour and giant-cell tumour seen at the Middlesex Hospital since 1925 are reviewed. Tumours arising from non-skeletal tissues in bone have been excluded.

2. The following histological classification is used. *Osteosarcoma* (osteoblast sarcoma): This tumour is not synonymous with osteogenic (bone-forming) sarcoma. The essential feature is the formation of osteoid tissue by malignant osteoblasts, with no intermediate matrix of cartilage or fibrous tissue. It is the most malignant bone tumour and only four of the thirty-two patients survived three years. *Chondrosarcoma:* These tumours are composed of cartilage, and some show secondary ossification. The behaviour of this group is related to the degree of cartilaginous differentiation. In general, compared with the osteosarcoma, it is of low-grade malignancy. More than half of the sixty-eight patients survived four years. *Fibrosarcoma:* The essential feature of this tumour is the production of collagen by malignant fibroblastic tumour cells. Tumours of this type invading the medullary cavity have an average prognosis between that of an osteosarcoma and a chondrosarcoma. Nine of the thirty-four patients survived three years. *Spindle-cell sarcoma:* These tumours are composed of spindle cells which produce no diagnostic matrix. In spite of the lack of differentiation the outlook is not hopeless. Six of the eleven patients survived for five years or more. *Giant-cell tumour:* This tumour is composed of a cellular stroma with diagnostic giant cells resembling osteoclasts. It is by no means a benign lesion, for half the tumours recurred after treatment and a quarter of the patients died with metastases.

3. The subdivision of primary malignant skeletal tumours into groups according to the histological pattern appears to be reflected in the behaviour of the individual tumours after treatment. The prognosis of each group has been stated in the appropriate sections.

We wish to thank Professor R. W. Scarff for advice and helpful criticism and Dr A. C. Thackray for some of the photomicrographs. We are indebted to members of the surgical staff of the Middlesex Hospital and to Professor B. W. Windeyer for permission to include clinical details of the patients under their care, and to Mr L. Atkinson for abstracting some of the case histories. We gratefully acknowledge the invaluable help received from Dr P. S. Andrews with the many specimens of bone tumours; also the photographs by Mr M. Tierney, and advice on the radiographic appearances of the specimens from Dr C. G. Whiteside and Dr J. N. Pattinson. We would like to thank Mr T. E. Cowan for his unfailing assistance with the case records and the follow-up details. The expenses of this investigation were defrayed by the British Empire Cancer Campaign.

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AN AUTORADIOGRAPHIC STUDY OF MUCOPOLYSACCHARIDE AND PHOSPHATE COMPLEXES IN BONE GROWTH AND REPAIR

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The experimental study of bone growth and repair began with Belchier's observation in 1736 of the staining with madder root of bones *in vivo*. This technique was used by such men as Duhamel and John Hunter, and, with the development of the microscope, morphological studies on bone were carried out by Goodsir, Ollier, Macewen and many others (Keith 1919). A more recent review of these and of later experimental investigations was made by Bertelsen in 1944.

More specialised techniques and methods, such as Fell's (1925) *in vitro* tissue culture technique and the *in vivo* anterior eye transplantation method of Urist and McLean (1952), have provided much information about the origin and function of the principal cellular components of bone. However, this is still a controversial matter, and, although the histological process of endochondral ossification, growth and repair is well recognised, there is still much uncertainty and lack of knowledge of the histochemical aspect. The true histochemical study of bone growth and repair began with the development of new and specific staining methods (Lison 1936, Gomori 1939), and these have been much used in the past few years (Wislocki *et al.* 1947, Pritchard and Ruzicka 1950).

Bone is composed of osteogenic cells and an intercellular substance consisting chiefly of collagen which may be sulphonated (Ham 1953). Between the fibrils of collagen there is a deposition of mineral salts in the form of crystals of hydroxyapatite (Robinson 1952) which is of the nature of tricalcium phosphate hydrate with salts of calcium carbonate and magnesium in the surrounding amorphous cement substances (Hendricks and Hill 1951). Sylvén (1947) renewed interest in the metabolism of chondroitin sulphuric acid in cartilage, and more recently Follis (1952) described cartilage as consisting of collagen, a mucopolysaccharide—chondroitin sulphuric acid—and lipoid material with minerals. A mucopolysaccharide is considered to be a hexosamine-containing carbohydrate or polysaccharide which may or may not be combined with a protein (Pirie 1946). In the group in which the carbohydrate is combined with a protein, as well as chondroitin sulphuric acid there are hyaluronic acid, mucoitin-sulphuric acid and heparin.

The original concept of Robison and Rosenheim (1934) that the enzyme alkaline phosphatase was concerned with calcification by increasing the local concentration of inorganic phosphate has been broadened. The enzyme is now considered to be closely concerned with pre-osseous cellular metabolism, with subsequent elaboration of a bone matrix and resulting precipitation of calcium and phosphate ions (Siffert 1951). However, since the histological change from cartilage to bone is accompanied by a biochemical change from mucopolysaccharides to calcium phosphate complexes, this can be studied *in vivo* by the use of suitable radioactive isotopes.

Various earlier workers have described the distribution, metabolism and excretion of radioactive sulphur (^{35}S) and phosphorus (^{32}P) in bone. In particular, Dziewiatkowski (1951, 1952, 1953) has shown by autoradiography that ^{35}S is incorporated in sections of articular cartilage and other organs of the rat, and he relates its uptake to the mucopolysaccharide chondroitin sulphuric acid. Boström (1952, 1953) confirmed and demonstrated this observation quantitatively, and has shown how the fixation of this isotope is dependent upon an enzyme system which is influenced by temperature, by oxygen pressure, and by drugs such as cortisone

and salicylic acid. Further autoradiographic studies by Bélanger (1954) demonstrated more accurately the localisation of this isotope in the tissues, especially in the cartilage cells. By incubating sections with hyaluronidase and staining for metachromasia with toluidin blue, he concluded that radioactive sulphur represents a sulphated polysaccharide—probably chondroitin sulphate type A of Meyer and Rapport. He also emphasised the intimate relationship of the sulpho-polysaccharides to the onset of mineralisation. Layton (1950) using an *in vitro* tissue culture technique, described how regenerating muscle tissue of chicken embryo absorbed and fixed inorganic radioactive sulphur, and he showed that the amount could be decreased by adding cortisone or salicylic acid to the medium.

Leblond and his co-workers (1950) described the incorporation of radioactive phosphorus into the crystalline calcium phosphate complexes used in the formation of bone salts during bone growth.

In the present study we have used ^{35}S and ^{32}P for autoradiography of undecalcified bone sections in an attempt to obtain further information on the histochemistry of bone during its growth and repair, and in particular to demonstrate more clearly the relationship of mineralisation to the mucopolysaccharides.

MATERIALS AND METHOD

Animal data—Eighteen rats, of both sexes, from two litters of an Albino strain were used in the sulphur series, their weights all being within 2 grammes of 50 grammes and their ages about five weeks. Under ether anaesthesia their right radii and ulnae were fractured with bone-cutting forceps. Each of nine rats was then injected intraperitoneally with 0·5 millilitres of sterile normal saline containing 1,500 μc of ^{35}S (30 μc/g. body weight) supplied by the Radiochemical Centre, Amersham, as sulphate in aqueous solution, carrier free; and each of the other nine rats was injected intraperitoneally with 0·5 millilitres of sterile normal saline to provide controls for the radioactive group. The groups were kept separately but under identical conditions, and one animal from each group was sacrificed at selected intervals after injection. The intervals chosen were nineteen, forty-three and ninety-six hours, seven, fourteen, twenty-eight, thirty-eight, forty-two and sixty-six days, some of which were arranged to fit into the subsequent processing programme.

Each rat was killed with chloroform, and immediately the right radius and ulna and the right tibia were dissected out. These bones were then placed in 10 per cent neutralised formalin.

In the preliminary phosphorus series sixteen rats were used, their weights varying between 95 and 140 grammes and their ages being about six weeks. The procedure was the same as in the sulphur series, but the eight radioactive rats were given injections of either 2 μc/g. or 4 μc/g. body weight of ^{32}P in a sterile normal saline solution, depending upon whether the rat was to be sacrificed within the first seven days or kept for more than fifteen days. The increase in dosage was to compensate in part for the radioactive decay of the phosphorus which has a half life of 14·3 days. The ^{32}P was supplied by the Radiochemical Centre, Amersham, carrier free in a dilute hydrochloric acid solution.

The rats were weighed and examined at the time of sacrifice to detect any possible radiation effects and the stained sections were scanned for any signs of cellular death or interference with growth patterns. The low dosage rates which were used did not produce any detectable radiation effects.

The technique used in the preparation of the undecalcified bones to give 10 μ complete longitudinal sections has already been described by one of us (Duthie 1954) with details of the subsequent handling and dewaxing of the sections in preparation for autoradiography and staining.

To test for possible loss of radioactive material during the dewaxing and covering with photographic emulsion, two slides from each specimen were counted in a standard position under the thin window of a type E.H.M. 2 Geiger-Müller counter before they were dewaxed and covered; they were then recounted after the photographic emulsion had been removed (before it had dried out). In most cases in the sulphur series an increase in counts was obtained because of the removal of the embedding wax which absorbed the low energy beta particles before processing, but losses of phosphorus were recorded.

Micro-autoradiography—By the technique of autoradiography visual localisation of radioactive forms of various chemical elements within tissues is possible. The radiations emitted by radioactive isotopes have a photographic action like that of light and therefore reduce the silver halide crystals in the photographic emulsion to metallic silver grains which appear black. The degree of blackening

or number of grains seen, after development, is proportional to the amount of radioactivity in the underlying tissue, and therefore a quantitative as well as a localising picture can be obtained. Experience and care are required in the interpretation of the results because artefacts may be produced by both chemical and physical agents.

The stripping film technique described by Pelc (1947) was used with few modifications. The Kodak Autoradiographic Emulsion was cut and floated face down on a cold distilled water surface; the slides bearing the sections were slipped one by one under the swollen pieces of gelatin and lifted out carefully, now covered with film, and placed in a rack to dry. When almost dry the slides were arranged in wooden slide boxes, wrapped in black cloth and stored in a light-tight cupboard at room temperature.

Exposure times were estimated to give some weak autoradiographs suitable for possible grain counting under high power and oil immersion, and stronger ones for photomicrography. All the photomicrographs were taken with the grains in the photographic emulsion in focus so that the cellular tissue just below the focal plane is not so sharply defined (e.g., Fig. 4). Since many sections

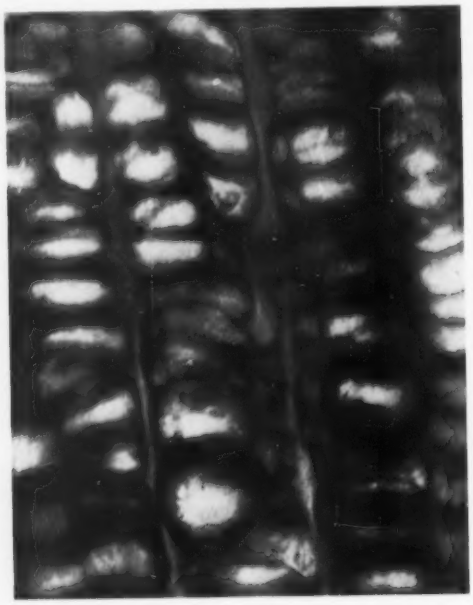

FIG. 1

Section of middle zone of the proximal epiphysial plate of a control rat's tibia. No black grains are seen. (×600.)

can be obtained from each bone by the cutting technique used, a wide range of exposure times was possible, and in fact images from just above background to images clearly visible to the naked eye could be produced by sampling at frequent intervals or by covering different groups of slides at different times after sectioning.

Development was carried out in a solution of one part of Kodak D 19b to two parts of distilled water at approximately 65 degrees Fahrenheit, and after rinsing in cold distilled water fixation was completed in a solution of one part of Johnson's Fix Sol to four parts of cold distilled water. Washing in cold running tap water was continued for about one hour before staining was started.

The bone sections were then stained through the wet photographic emulsion with the toluidin blue-eosin stain of Lillie (1948) for approximately three hours, rinsed in cold tap water and dehydrated through the following series of neutralised solutions: 75 per cent alcohol, 95 per cent alcohol, isopropyl alcohol, isopropyl alcohol and xylol in equal parts, and pure xylol, allowing about ten minutes in each. It was found that by this sequence and timing the sections were satisfactorily stained and any blue dye taken up by the gelatin of the film was almost completely

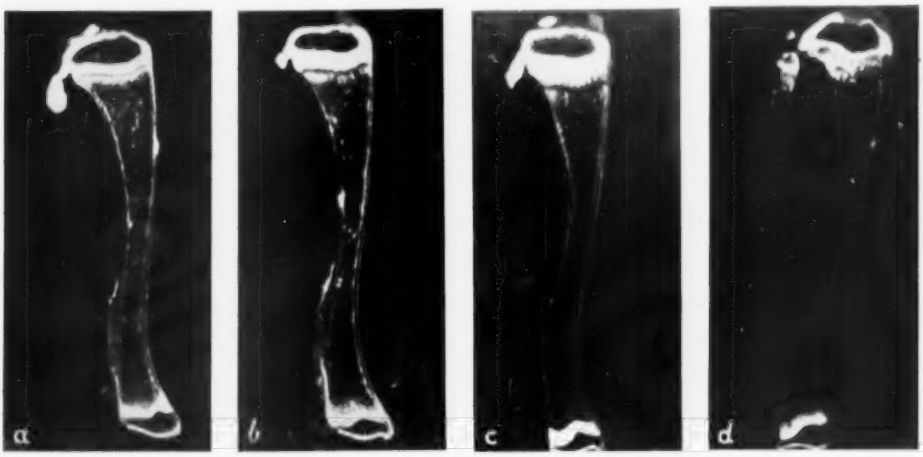

FIG. 2

Enlarged prints (× 3) of macro-autoradiographs with ^{35}S obtained by exposing sectioned rats' tibiae in ester wax blocks in direct contact with Ilford contrast x-ray dental film. White areas correspond to the localisation of the radioactive sulphur. Figure *a* shows deposition of isotope in articular cartilage, epiphysial plate, head of fibula, both layers of periosteum and diffuse small punctate areas within the marrow cavity. The line of vascularity is seen immediately subjacent to the epiphysial plate in proximal end. Figure *b* is similar except that the distal end now shows similar appearance to proximal end with line of vascularity. Proximal end on lateral side of metaphysial area shows heavy deposition. Figure *c* shows broadening of epiphysial plate of both ends with some loss of activity all over bone. Figure *d* shows further losses in all areas but the deposition on lateral side of the metaphysial region is still marked.

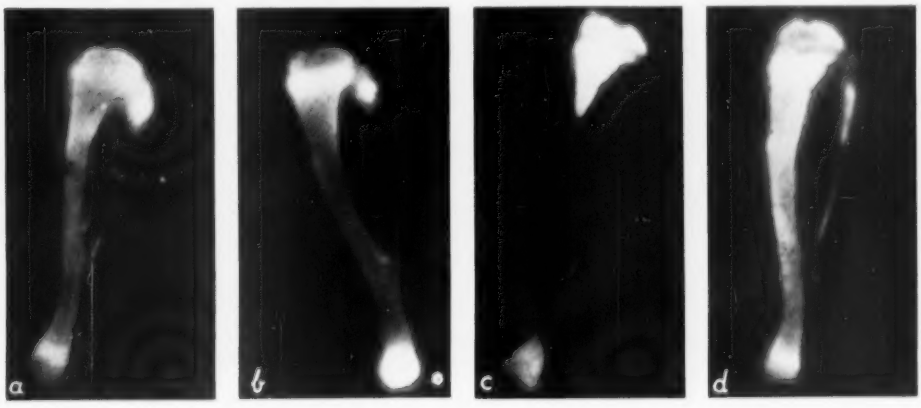

FIG. 3

Enlarged prints (× 2) of macro-autoradiographs with ^{32}P obtained by the same procedure as those of Figure 2. The white areas correspond to the localisation of radioactive phosphorus. The images are more diffuse, with poorer resolution than those obtained with sulphur, for the energy of the beta radiation emitted by phosphorus is much greater than that of sulphur. The Figures show localisation of isotope throughout the bone with greater concentration in metaphysial regions, with some displacement occurring after twenty-four hours into the diaphysis.

removed and did not impair the microscopic examination of either the section or the superimposed autoradiograph. To protect the emulsion, the cover slips were sealed immediately with D.P.X.

Control sections from the inactive rats were processed each time along with the active ones to give an indication of background grain levels and to aid in recognition of any artefacts produced in the processing. Although only one control autoradiograph is illustrated (Fig. 1) each " positive "

autoradiograph was compared with its normal control. As an aid to comparison, the degree of blackening (or the reaction) in the image was assigned a number between 0 and 5 on an arbitrary intensity scale, thus providing a rough quantitative picture of the relative concentration of the isotope within each microscopical section. This type of quantitative classification is limited in that in a 10 μ section there is considerable overlapping of the cells, their walls and the intervening spaces, so that the reaction may arise from any or all of these components to give the overlying positive autoradiograph. The variations in grain density produced by the different exposure times were taken into consideration in the quantitative estimations.

Macro-autoradiography—After the required number of sections had been cut from each bone embedded in its ester wax block, the blocks were kept and used to make macro-autoradiographs. The face of each block was placed against a piece of Ilford Contrast Dental Film Type 15 P on a clean microscope slide. Movement of the block during exposure was prevented by binding the block firmly to the glass slide with "Sellotape." Wrapped in black paper the blocks were kept in a light-tight tin during exposure. Exposure times were long enough to give negatives suitable for enlargement, and these varied over a wide range because the times between injection and sacrifice and between sacrifice and mounting varied considerably from rat to rat, as well as the distribution of the isotope within the bones. Attempts to estimate the best exposure times by counting the activity remaining in the bone under a thin end-window Geiger-Müller counter were of little value because the residues of bone in the blocks were far from constant and the surface areas varied. In some cases the whole shaft had been used up in obtaining enough suitable sections for micro-autoradiography, leaving only the ends of the bones.

FIG. 4

Section of articular cartilage from proximal end of rat's tibia, showing a diffuse and high grain density from ^{35}S over the cartilage area with few grains over bone of the epiphysis (bottom left). ($\times$400.)

To begin with, control blocks were mounted along with the active ones, but this was subsequently found to be unnecessary because pressure marks and other artefacts were easily distinguished from the true autoradiographs. The photographic processing of these exposed x-ray films was the same as described above for the stripping film emulsion. Enlargements from the negatives were made to facilitate visual examination (Figs. 2 and 3).

Areas of tissue which contain too little radioactive material within a 10 μ section to give a positive micro-autoradiograph may nevertheless give positive macro-autoradiographs because the mass of tissue contributing to the image in the latter is much greater and the x-ray emulsion is many times more sensitive.

To compare the distribution of isotope visualised by this procedure with the calcium density of actual bone present the blocks were radiographed. The wax blocks were laid out face down on a wrapped sheet of Ilfex double-coated x-ray film and a short exposure at 60 kv. was taken with the tube at a distance of about five feet, the beam current being 20 mA. The exposed films were processed as previously described and the negatives enlarged for comparison with the macro-autoradiographs.

RESULTS

Sulphur^{35} in bone growth. *Proximal end of tibia*—Sulphur was incorporated in the articular cartilage within nineteen hours (Fig. 4), reaching a maximum twenty-four hours later and thereafter decreasing steadily to zero after thirty-eight days.

The columns of cartilaginous cells in the epiphysial plate were divided into five phases according to Streeter's (1949) classification. Although this classification was based upon the

different phases of cartilage cell morphogenesis extending around the primary ossification centre in a cartilaginous model, it is most applicable to cellular change in the epiphysial plate region (Fig. 5). After nineteen hours a considerable amount of the sulphur was present in the intercellular areas and slightly more had been incorporated in the region of the walls of the cartilage cells (Fig. 6). This high concentration persisted in these areas for the first seven days and gradually decreased to a minimum at forty-two days. Phases I and II in the nineteen-hour rat cartilage were also markedly positive, and this high density wave appeared to progress down the column until at ninety-six hours the greatest activity was in Phases III and IV (Fig. 7). The activity of the areas of calcifying cartilage matrix between the cells of Phase V was not significantly different from other areas. As the time intervals were increased the activity diminished until after forty-two days only a very narrow positive region persisted.

Continuous with the above cartilaginous intercellular substance or partitions there were islets or trabeculae of cartilage extending down into the metaphysis and diaphysis of the shaft. These did not show any positive photographic reaction at nineteen hours (Fig. 8), but at forty-three hours their intensity was much greater than in the other cartilage areas (Fig. 9), and this reaction persisted in intensity for a long time before disappearing completely by the twenty-eighth day (Fig. 10).

Another region in the metaphysial area which showed greater activity than others was seen below the epiphysial plate on the lateral side of the upper shaft and is of interest in the particular pattern of growth of this region.

Immediately beneath the zone of disintegrating cartilage cells and in line with the proximal ends of the trabeculae there was seen both macroscopically (Fig. 1*a*) and microscopically (Fig. 11) a relatively inactive line which corresponded to the first appearance of thin-walled sinusoidal blood vessels containing red blood corpuscles—that is, *the line of vascularity*. Some increase in intensity occurred within the first seven days, but this was small and gradually decreased to zero in line with other areas.

Periosteum—Both layers were radioactive at nineteen hours, especially the inner (Fig. 12). Throughout the following stages they were approximately equal, and some activity still persisted in patches of both after forty-two days.

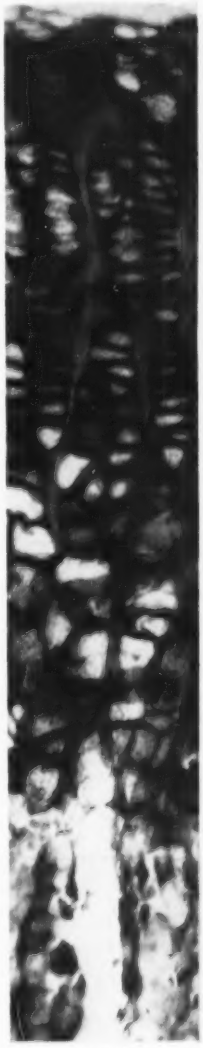
PHASE I. Young small cartilage cells with obvious intercellular substance.
PHASE II. Cartilage cells still young and small and more regular in a transverse plane with more intercellular substance.
PHASE III. Cells now cuboidal and incompletely separated by intercellular substance.
PHASE IV. Cells now of maximum size with intercellular substance forming a honeycomb framework.
PHASE V. Disintegration or breakdown of cells.
Line of vascularity with first appearance of red blood cells.
Trabeculae of cartilaginous remnants.

FIG. 5

Section of proximal epiphysial plate to show Streeter's classification and also the line of vascularity and trabeculae of cartilaginous remnants distal to the plate. Grains from ^{35}S can be clearly seen in the intercellular areas and over the cell walls. (×300.)

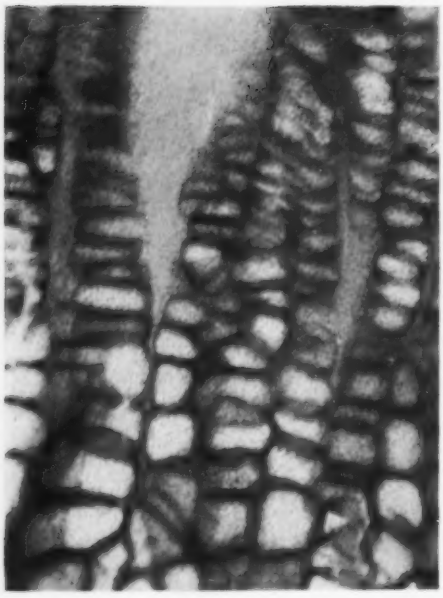

FIG. 6

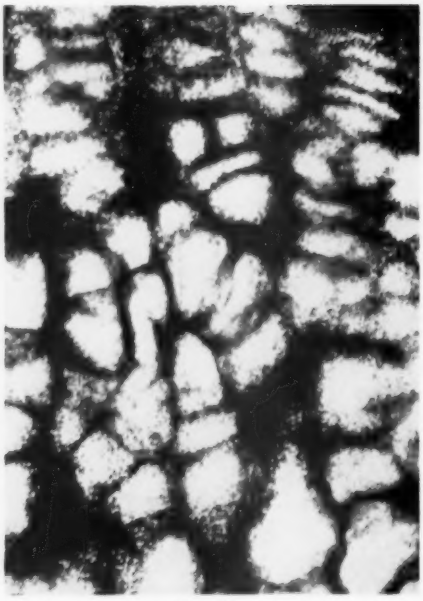

FIG. 7

Figure 6—Section of middle zone of epiphysial plate. Heavy distribution of grains from ^{35}S is seen over intercellular areas and over walls of cartilage cells, particularly in Phases II and III. (Toluidin blue and eosin × 350.) Figure 7—Similar to Figure 6, but seventy-seven hours later. The greatest density from ^{35}S is now more distal over cells of Phases III and IV.

Mast cells—These cells were numerous both inside and outside the bone substance and showed an uptake of sulphur which was weak at nineteen hours, strong at forty-three and ninety-six hours (Figs. 13 and 14), then gradually diminished, disappearing completely by the twenty-eighth day. The amount of activity present in these mast cells was closely related to that in the hypertrophying cartilage cells.

Aortic wall—Other tissues which contain mucopolysaccharides were examined, and the wall of the aorta, especially over the muscular coat, showed a moderate degree of activity (Fig. 15) from utilisation of ^{35}S by this tissue.

Bone marrow—The cells of the bone marrow at the forty-three hour period had some activity which soon decreased, being negligible by fourteen days.

Distal end of tibia—The blackening over the various areas was similar to that of the proximal end, except that the features described above were twenty-four hours later in appearing, as illustrated clearly by later appearance of the line of low activity or vascularity (Fig. 1*b*).

FIG. 8

FIG. 8

Section through distal area of epiphysial plate in Phase V, with line of vascularity and trabeculae at nineteen hours. No grains are seen over the trabeculae of cartilaginous remnants, although grains from ^{35}S can be seen over the cartilage cells of Phase V. (× 400.)

FIG. 9

FIG. 10

Figure 9—Section of trabeculae of cartilage distal to epiphysial plate at forty-three hours. There is now seen a heavy distribution of grains from ^{35}S. (×400.) Figure 10—Similar to Figure 9, but at twenty-eight days. There is now no activity in the trabeculae.

FIG. 11

FIG. 12

Figure 11—Section of distal aspect of epiphysial plate and upper metaphysial area, showing red blood cells in line of vascularity with trabeculae and grains from ^{35}S only over cells of distal epiphysial plate. (Toluidin blue and eosin ×400.) Figure 12—Section through both layers of periosteum with cortex on right. Heaviest grain density from ^{35}S is seen over inner layer of periosteum and cortex. (×400.)

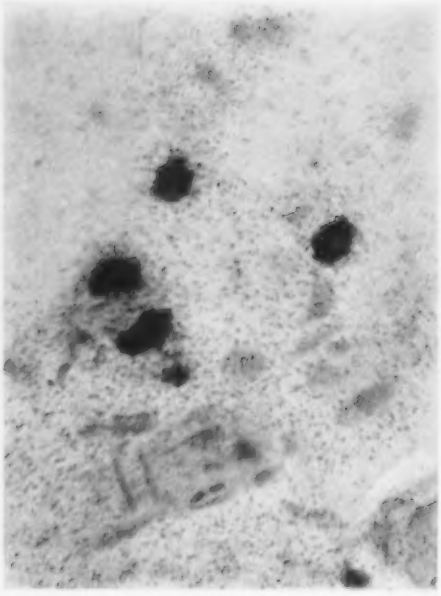

FIG. 13

FIG. 14

Section of pertaortic tissue (Fig. 13) and marrow cells (Fig. 14) to show heavy grain density from ^{35}S over mast cells which are exhibiting metachromasia with deep purple colouration. (Toluidin blue and eosin. ×615.)

Phosphorus^{32} in bone growth—Since the average beta particle energy of phosphorus is much higher than that of sulphur, the ^{32}P images were more diffuse and therefore the resolution was poorer and interpretation at the cellular level became more difficult than with ^{35}S.

After twenty-four hours—In the epiphysial plate region there was little activity and this was confined to Phases IV and V cartilage cells. In Phase IV the activity was widespread and diffuse extracellularly over the walls and within the cells, but in Phase V there was evidence of nuclear accumulation of phosphorus as well as in the calcified cartilage between the large degenerating cells (Fig. 16). There was a slightly greater reaction over the line of vascularity. The greatest reaction was seen over the trabeculae of calcifying cartilage (Fig. 17), and this persisted distally into the diaphysis. The articular cartilage and soft tissues showed much less activity. The outer layer of periosteum had little activity, but the inner layer showed greater reaction and in the submetaphysial region there were clearly seen "cone-shaped" areas of cellular

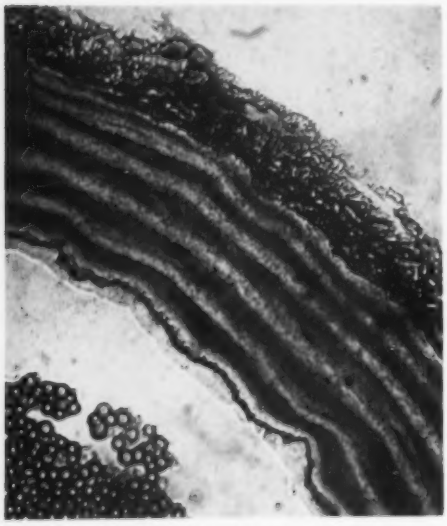

FIG. 15

Section through wall of aorta, to show moderate grain density from ^{35}S over muscular part of wall, with no grains overlying red blood cells in lumen. (Toluidin blue and eosin. ×400.)

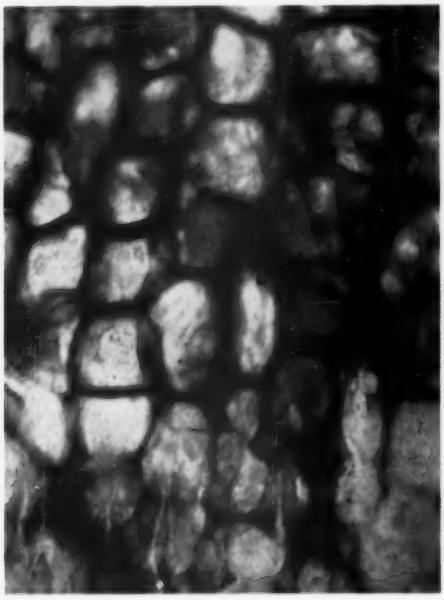

FIG. 16

FIG. 17

Figure 16—Section through distal aspect of epiphysial plate and line of vascularity. Diffuse grain density from ^{32}P over Phases IV and V with high grain density over some nuclei. (× 400.) Figure 17—Section distal to epiphysial plate, in metaphysial area, showing great grain density from ^{32}P around trabeculae of cartilaginous remnants which are being calcified. (× 400.)

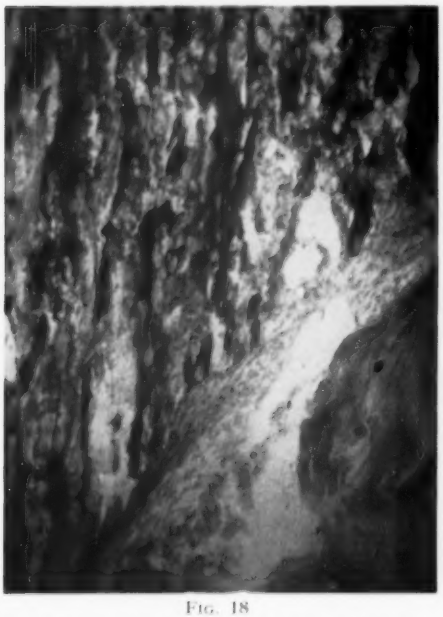

FIG. 18

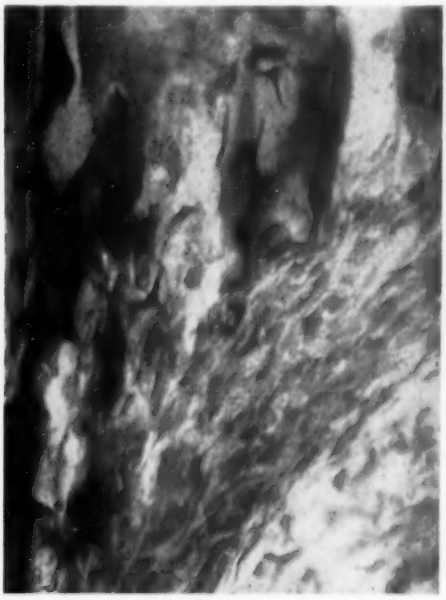

FIG. 19

Figure 18—Section in metaphysial area with layer of periosteum across right corner and muscle outside this. This shows trabeculae of calcifying cartilage running down on to periosteum to form cone-shaped areas. Grains are not visible at this magnification. (× 100.) Figure 19—Section in same area as Figure 18, with calcifying trabeculae running down on to cellular periosteum. Grains from ^{32}P seen around trabeculae and over periosteum. (× 400.)

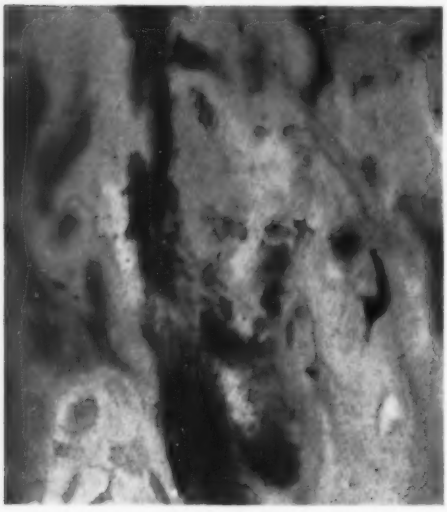

FIG. 20

Section in diaphysis after fifteen days with one area of calcified cartilage and cortical bone on each side. Grains from ^{32}P seen over mature bone. (× 400.)

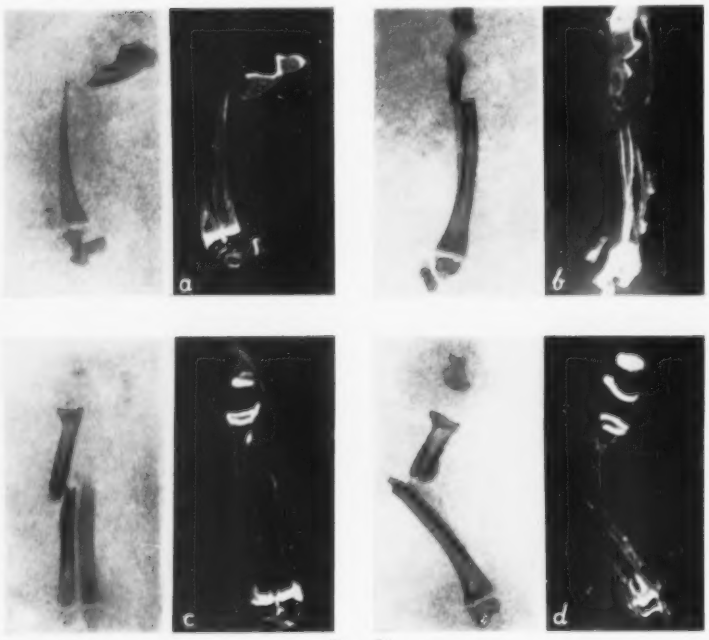

FIG. 21

Enlarged prints (× 3) of macro-autoradiographs with ^{35}S in fractured radii and ulnae, compared with enlarged radiographs (× 3) of the same bones (left of each Figure). In Figure *a* the autoradiographs show that although the various areas in the bone, such as epiphysial plate, periosteum and articular cartilage, have high content of radioactive sulphur, there is no deposition around the fracture site. The radiographs show early bone union by two weeks (*d*), with distribution of new bone subpericosteally and between fracture line.

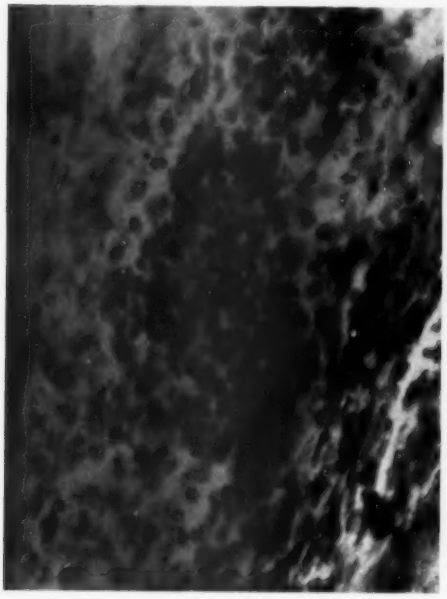

FIG. 22

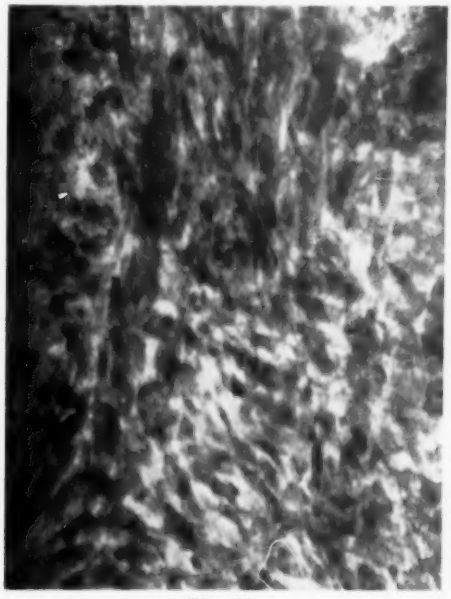

FIG. 23

Figure 22—Section through fracture site of radius and ulna to show the pro-callus stage with bone fragment (bottom right) and cellular infiltration, but no grains are seen. (×400.) Figure 23—Section through fracture site at ninety-six hours to show later stage with increased cellular infiltration of osteoblasts and fibroblasts; no grains are seen. (×400.)

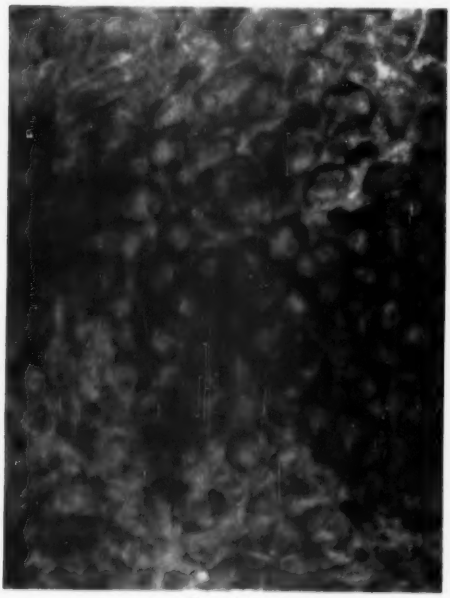

FIG. 24

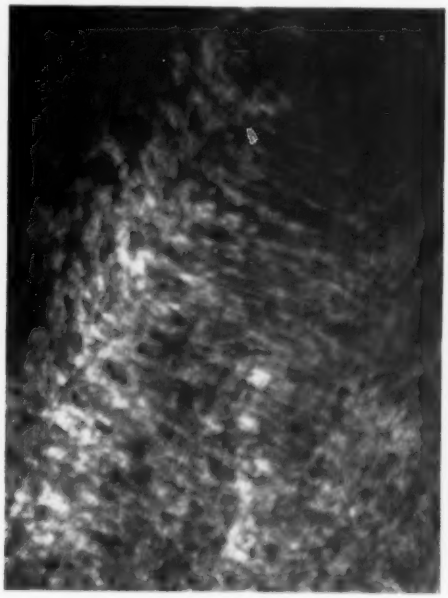

FIG. 25

Figure 24—Section through fracture site at seven days to show fibrocartilaginous stage with formation of cartilage cells and early pale metachromasia with purple colouration; no grains are seen. (×400.) Figure 25—Section through fracture site at fourteen days, with fibrocartilaginous callus formation with cartilage cells (top left) and cellular proliferation but no grains.

structure—osteoblasts and cartilaginous remnants leading down on to the inner layer of periosteum, which were positive. The marrow cells showed minimal activity at this period but the mast cells were negative.

After forty-eight hours—The reaction of Phases IV and V cartilage cells in the epiphysial plate had diminished and there was no activity outside the cells. The trabeculae of calcified cartilage extending down into the diaphysis were still strongly active and the distal end of the tibia now showed an activity and appearance like that of the proximal end after twenty-four hours. The articular cartilage still possessed some activity, but this was less and the marrow cells were now negative. The reaction of both the inner and outer layers of periosteum had decreased but the "cone-shaped" areas were still active (Figs. 18 and 19). The line of vascularity also showed less reaction.

FIG. 26

Enlarged prints (× 2) of macro-autoradiographs with ^{32}P in fractured radii and ulnae, side by side with enlarged radiographs (× 2) of the same bones (left of each Figure). In Figures *a* and *b* the macro-autoradiographs show that there was an increased reaction around the fractured site by forty-eight hours (*b*), followed by diffusion (*c*), and then a further intense reaction (*d*) around the fracture site. The radiographs show progressive bone formation and union by three weeks.

After ninety-six hours—The trabeculae exhibited less activity, as did the inner layer of periosteum and the line of vascularity, and these were the only remaining positive regions.

After seven days—The only reaction was over the calcified trabeculae and periosteum.

After fifteen days—The only reaction was over recognisable mature bone along cortex and calcified trabeculae (Fig. 20). This persisted until the twenty-second day.

Sulphur^{35} in bone repair—No reaction around the fracture site was seen on examination of the enlarged prints of the macro-autoradiographs (Fig. 21), although by two weeks there was radiographic evidence of early bony union with deposition of calcium salts (Fig. 21*d*) which agreed with Copp and Greenberg's (1945) observation on the rate of healing of fractures in rats. Microscopically, by nineteen hours there was marked activity over the cartilage and

periosteum, and some activity over the marrow cells, but no reaction over the soft tissues adjacent to the fracture site although there was cellular infiltration with red cells and bone fragments of the pro-callus stage (Fig. 22).

By ninety-six hours (Fig. 23) microscopically there was little reaction although immature cartilaginous cells had appeared in the vicinity of the fracture site, to form the fibro-cartilaginous callus stage. The activity was not any greater than that of the marrow cells, and did not increase.

By seven days (Fig. 24) at the fractured area definite cartilage formation appeared with early pale metachromasia around the cells, but there was no evidence of incorporation of radioactive sulphur.

A week later no activity had appeared although further development of osteoid tissue with early metachromasia and cartilaginous callus formation (Fig. 25) had taken place.

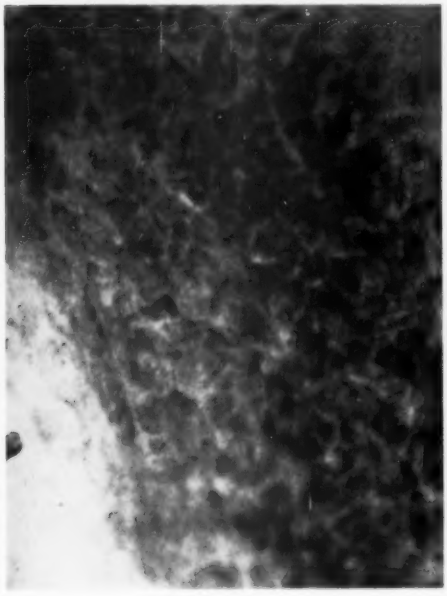

FIG. 27

FIG. 28

Figure 27—Section through fracture site at forty-eight hours showing pro-callus stage with cellular proliferation and diffuse distribution of grains from ^{32}P. (×400.) Figure 28—Section from fracture site at twenty-two days with new bone formation above and to right and cartilaginous callus below. Grain density from ^{32}P heavier over bone.

New bone formation occurred by four weeks with metachromasia over the cartilage area, but the activity was equal only to that of the background. Two weeks later there was little reaction in any part of the section.

Phosphorus^{32} in bone repair—By forty-eight hours there was an increased deposition of this isotope around the fracture site macroscopically (Fig. 26) and this was confirmed microscopically (Fig. 27). This area then showed a decrease in intensity with a diffusion of the activity throughout the whole bone. By twenty-two days (Fig. 28) there was another increase in activity around the fracture site and microscopically this reaction was occurring primarily over the new bone formation without any marked activity over the cartilaginous cells. By this time there was radiological evidence of early bony union of the fracture with deposition of calcium salts (Fig. 26*d*).

DISCUSSION

Sulphur^{35}—The gradual alteration in position and intensity of radioactivity through the extracellular and cellular substances and then downwards through the epiphysial plate appears to represent secretion and utilisation of ^{35}S in chondroitin sulphuric acid. This substance is thought to be secreted by the maturing chondrocyte, but we cannot confirm this from the present study because of the unavoidable physical overlap of cells which gave an equal reaction over both the extracellular and cellular substances. The gradual movement of activity we regard as resulting from metabolism of the cells with diffusion through the gel of the intercellular matrix. Wharton's jelly, which consists of another mucopolysaccharide—mucoitin sulphuric acid—was regarded by Barcroft *et al.* (1944) as a non-vascular pathway for nutritional substances, its physical process of diffusion probably being like that seen in the cartilaginous matrix because of its chondroitin sulphuric acid content. Ekholm (1951) demonstrated this diffusion property through the articular cartilage of a rabbit's knee joint by the use of radioactive gold.

In Phase V of the epiphysial plate there was seen disintegration of the degenerating cell, with extracellular liberation of radioactive sulphur into the matrix. In this area we also saw deposition of phosphate complexes, and Ham (1953) ascribed the degeneration of the cells here to the deposition of calcium phosphate around them, which cut off all nutrition. At this level there was the first appearance of thin-walled blood vessels, reaching up to disintegrating cartilage cells, with a sudden decrease in radioactivity which suggested that there was removal of the radioactive sulphur by the blood with subsequent utilisation elsewhere. This line corresponded to the area described by Hobo (1921), who ascribed to this vascular arrangement the localisation of pyogenic organisms to give a primary focus of an osteomyelitis. Apart from the thin-walled nature of the vessels, the nidus of disintegrating cells and nutritional debris forms an ideal culture medium.

Although alkaline phosphatase is concerned with deposition of phosphate ions during calcification because of its localisation in the nuclei of the palisading cartilage cells and in the matrix between the degenerating cells, Siffert (1951) related its function also to matrix formation. However, he pointed out that histological demonstration of an enzyme did not necessarily indicate its activity. Kroon (1952) also regarded this enzyme as necessary in the formation of the mucopolysaccharides in bone. But the early and marked appearance of labelled chondroitin sulphuric acid in the upper phases of hypertrophying cartilage cells indicated that there was formation of this mucopolysaccharide before this enzyme had appeared extracellularly, and therefore the presence of alkaline phosphatase is not necessary for the earlier phases of chondroitin sulphuric acid metabolism.

The late appearance of radioactivity at forty-three hours in the metaphysial islets or trabeculae of cartilaginous cells and remnants indicated that there was some metabolic process continuing with utilisation of the radioactive sulphur, in spite of the deposition of calcium phosphate complexes around their surfaces.

The bone marrow cells had minimal activity by nineteen hours and a slight increase by forty-three hours, but there was no indication that bone marrow cells preferentially localised ^{35}S *in vivo*, although Lajtha *et al.* (1953) had obtained this result by a culture technique *in vitro* of human bone marrow cells. The uptake of ^{35}S by mast cells resembled in time and amount that of hypertrophying cells, and confirms Jorpes' *et al.* (1953) observation of the uptake of radioactive sulphur by the mast cells in the skin. In our series the activity was maintained until the twenty-eighth day. Granular disintegration was seen often, but there was no significant activity associated with these granules.

The activity of both layers of periosteum was marked both macroscopically and microscopically, and indicated active metabolism of some sulphated compound or a mucopolysaccharide like chondroitin sulphuric acid, but was less than in the endochondral areas. This would correspond to the slower rate of growth in this region and must be inherent in the cell activity rather than related to the richer blood supply.

The delay of twenty-four hours in the metabolism of the active sulphur at the distal end in comparison with the proximal end accords with the accepted anatomical fact that growth occurs earlier in the proximal than in the distal epiphysis of the tibia. In the metaphysial region on the lateral side increased reaction suggested greater metabolic activity and utilisation of the radioactive mucopolysaccharide. This is in agreement with anatomical observations on the patterns of growth by Bateman (1954) in which there is preferential enlargement of the anterior and lateral edge of a rat's proximal tibia by a process of "accretion," to give the curved outline.

Although all our sections were stained for metachromasia by toluidin blue, we could not relate intensity of colouration to degree of radioactivity in any area.

Phosphorus^{32}—Leblond *et al.* (1950) described how, because of its insolubility in formalin, ^{32}P was incorporated into part of the crystalline calcium phosphate formation making up the skeleton. He also noted that there were two stages of localisation of this insoluble phosphate deposition—a labile fraction which produced a diffuse reaction throughout the bone but which had disappeared within a few hours, and a stable fraction which remained localised and represented true addition of new bone salts. It was this stable fraction which was studied in this experiment.

The low grain density, as described over Phases IV and V of the degenerating cartilage cells, both intercellular and cellular, can be correlated with the presence of alkaline phosphatase in these regions, as described by Siffert and others. But the minimal amount of activity between the degenerating cartilage cells of Phase V indicates that there is little phosphate metabolism during the calcification process at this level. The blood vessels are subjacent to this area and therefore precipitation of the phosphate complexes appears to have occurred distally and then to have diffused upwards between the degenerating cells. This is in contradiction to Leblond's work in which he ascribed his "black" line of radioactivity to the deposition of radioactive calcium phosphate complexes in the calcifying cartilage between the hypertrophying cartilage cells. This line then moved distally into the lower phases before fading after twenty-four hours. The difference in these two experiments may be related to the differing age of his series of animals and to the differing time delay before sacrifice.

The greatest deposition of radioactive calcium phosphate complexes was around the trabeculae of cartilage remnants and was related to the close proximity of the blood vessels which carry these minerals to these areas. This reaction persisted for a long time and extended far down into the diaphysis. No "tip erosion" as described by Leblond was seen, and it was not possible to localise the increasing amount of phosphate deposition to the outer surface of the trabeculae where new bone formation was occurring. The greater activity around the inner layer of periosteum corresponded to the greater osteogenic activity in this area necessary for the periosteal growth pattern.

In Leblond's "funnel-shaped" areas, subjacent to the epiphysial plate area, there were well marked "cone-shaped" areas consisting of numerous osteoblasts and trabeculae of cartilage, with their bases on the inner layer of periosteum and extending upwards into the metaphysial region. Their activity was high and confirmed the increased growth and metabolic rate of phosphates in this area which was described by Bateman as being a growth area of "accretion," endosteal in origin. The line of vascularity showed little activity and did not seem to absorb or accumulate phosphate locally.

After forty-eight hours there was gradual disappearance of activity, although the trabeculae were still strongly positive and the distal end of the tibia then corresponded to the appearance of the proximal end at twenty-four hours. There was less activity in Phases IV and V and it is probable that most of the activity present here was due to diffusion rather than to any active metabolic process.

Interrelationship of the metabolism of sulphur^{35} and phosphorus^{32}. *In bone growth*—The deposition of ^{35}S in the epiphysial plate and periosteal layers is regarded as indicating

the synthesis and utilisation of the mucopolysaccharide, chondroitin sulphuric acid. Movement or diffusion of this isotope occurred throughout, but the radioactive phosphate complexes appeared only between the degenerating cartilage cells in Phases IV and V. It was in this area that labelled chondroitin sulphuric acid had been released by the disintegrating cells, and it was here also that alkaline phosphatase appeared in an extracellular situation as described by Lorch (1947), Siffert (1951) and others. Immediately beneath this zone red blood cells in thin-walled capillaries appeared for the first time, and this implies that for the deposition of phosphate complexes which have been carried to the area by an obvious blood supply, chondroitin sulphuric acid must be lying free outside the disintegrating cartilage cells, with the presence of alkaline phosphatase in an extracellular situation.

This arrangement was again seen where the trabeculae of cartilaginous remnants and cells with their content of chondroitin sulphuric acid and alkaline phosphatase extended down in the metaphysial area, and there was deposition of phosphate complexes around these masses. Leblond *et al.* (1950) attributed the apparent shortening of the tips of the trabeculae to a " process of erosion," leading to cessation of longitudinal growth. However, we believe the cessation of further phosphate deposition and hence of growth to be caused by the disappearance of the chondroitin sulphuric acid content of the cartilage remnants—that is, that there is a quantitative balance between the amount of chondroitin sulphuric acid disappearing and the amount of phosphate which is being deposited. The actual amount of chondroitin sulphuric acid in these remnants of Phase V of the epiphysial plate is being added to by the metabolism of remaining intact cells, and this was suggested by the later appearance of radioactive sulphur. This arrangement was also seen in the cone-shaped areas of osteogenic cells and cartilaginous debris in the metaphysial area.

Hass (1943) noted in chemical studies that in the normal aging process of human costal cartilage there was a depletion of chondroitin sulphuric acid with a corresponding increase in calcium. The significance of the local pH is still unknown, but Sylvén (1947) ascribed the disintegration of the chondroitin sulphuric acid molecule, during inflammation, to the pH change from acid to alkaline. Whether the pH change is primary or secondary to the actual chemical change is uncertain.

In articular cartilage, although the metabolism of radioactive sulphur appeared to be identical with that in the epiphysial plate region and alkaline phosphatase has been described in the nuclei of the chondrocytes, calcification did not take place in this tissue under physiological conditions. No actual disintegration of the cartilage was seen, and, more importantly, no blood supply was observed. The importance of a blood supply to subsequent degeneration and calcification of the articular cartilage is well in accord with clinical and pathological observations. Greig in 1931 insisted that when bone was found within a loose body in a joint it must have been formed before the body had become detached from the blood supply of its parent membrane, and increase in size after detachment could occur only by cartilaginous deposition around it. Lacroix (1941) also noted, in experimental transplantation of cartilage blocks in bone defects, that new bone formation began only at the margin of the cartilage with the appearance of blood vessels, and this process then penetrated into the donor substance. More recently Harrison *et al.* (1953) showed that in osteoarthritis the degenerating articular cartilage was invaded by the subchondral blood vessels with subsequent calcification. Osteophyte formation also resulted from the proliferation of blood vessels into the degenerating articular cartilage at the margin of the joint.

In bone repair—We did not demonstrate any preferential uptake of radioactive sulphate in the healing fracture site over twenty-eight days, although Layton (1951) showed, by tissue culture *in vitro*, that regenerating muscle absorbed and fixed inorganic radioactive sulphate preferentially, and Lacroix (1954) described the localisation of radioactive sulphur in the developing oestrons or Haversian systems during osteogenesis in adult dogs. Healing proceeded normally, with the formation of a fibrocartilaginous callus which exhibited

metachromasia, and early bony union appeared by the second week. In contradistinction to this, the epiphysial plates above and below the fracture site were absorbing and utilising radioactive sulphur normally.

Pritchard and Ruzicka (1950) described in detail the histological picture of a healing fracture, and also the origin of the chondrifying matrix from the periosteal blastema—that is, the cells of the inner layer of the periosteum. Although these cells begin at a different morphological stage from the chondroblast in the epiphysial plate, they are perichondral in origin and therefore unlikely to have a different form of metabolism and to utilise radioactive sulphur in any different way. In our sections, the fibrocartilaginous callus exhibited metachromasia like that of the epiphysial plate region, but Wislocki *et al.* (1947) described how this property was exhibited by other mucopolysaccharides, for example hyaluronic acid, some mucoproteins, and yeast nucleic acids which did not have a sulphate linkage. Therefore the substance being used in the fracture site may differ from the chondroitin sulphuric acid of normal cartilage in lacking a sulphate linkage for labelling, but this is unlikely.

A more likely explanation of the failure to show preferential uptake *in vivo* of radioactive sulphur is that it was not available to the metabolising cartilage cell during the fibrocartilaginous callus stage of healing at the end of the first week. This could be related to the early lack of blood supply because of the fracture haematoma, and when blood vessels did enter this area the circulating blood serum level of radioactive sulphur would have fallen too low. Boström (1953) described the blood serum level of radioactive sulphur, after an intravenous injection, as being at its peak by ten hours with a rapid fall to forty hours and then a gradual decrease to zero by 200 hours. In our series, in which the radioactive material was injected intraperitoneally with slower absorption, the sulphate blood serum level was longer in reaching its peak.

Another possibility is that because of a very rapid utilisation and turnover, the accumulation of radioactivity in the site was too small to be demonstrated by autoradiography.

This failure to find the deposition of ^{35}S in a healing fracture site is being studied by a further series of experiments.

Phosphate metabolism in bone repair was seen in two phases. During the first forty-eight hours there was a preliminary deposition of radioactive phosphates which corresponded to the labile generalised fraction of Leblond, and the later time of appearance could be explained by the altered blood supply. At seventeen days there was another increased deposition of radioactive phosphate which accompanied the first radiographic appearance of bony union. It should be noted that there was deposition of phosphates into areas in which the presence of a mucopolysaccharide such as chondroitin sulphuric acid has not so far been demonstrated *in vivo*.

SUMMARY AND CONCLUSIONS

1. A method is described of demonstrating *in vivo* the utilisation of radioactive sulphur^{35} and of radioactive phosphorus^{32} during bone growth and repair.

2. The relationship between labelled chondroitin sulphuric acid and labelled phosphate complexes has been studied, the importance and significance of vascularity and the localisation of the enzyme alkaline phosphatase being noted.

3. It was found that bone growth by external accretion, both epiphysial and periosteal, was accompanied by an increased utilisation of radioactive chondroitin sulphuric acid and calcium phosphate complexes.

4. During repair in a fracture site, although there was deposition of radioactive phosphate, no preferential localisation of radioactive sulphur was observed and the possible explanations of this are discussed.

The work was carried out while one of us (R. B. D.) was holding the Crichton Research Scholarship of the University of Edinburgh.

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INVESTIGATION OF THE GROWTH AND STRUCTURE OF THE TIBIA OF THE RABBIT BY MICRORADIOGRAPHIC AND AUTORADIOGRAPHIC TECHNIQUES

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Previous investigations on the structure and growth of long bones have been made by many and varied techniques. As early as 1727 Hales first demonstrated experimentally by drilling holes to act as markers that in the growing bone the markers always remained at the same distance apart and that there was therefore no interstitial growth. This has been subsequently confirmed by many workers using the technique of markers of madder feeding (Duhamel 1742, Hunter in about 1772, Payton 1931–32, Brash 1934, Bisgard and Bisgard 1935) and of the radiographic study of the lines of arrested growth (Harris 1933). It was also noted that growth in width was different along the length of the bone (Duhamel 1743). Lacroix (1951) studied transverse growth in detail by routine histological techniques. It is now accepted that, in general, transverse growth depends on the formation of new bone on the endosteal surface of the metaphysial funnel and on the periosteal surface of the cylindrical shaft, together with simultaneous removal of bone from the periosteal and endosteal surfaces respectively at the same sites.

Studies with radioactive isotopes have confirmed these findings and added many new details. Radioactive phosphorus has been used as a tracer to demonstrate the growth of the tibia-fibula in rats (Leblond *et al.* 1950). A single intravenous injection of the radioactive isotope was given and the animals sacrificed at various times after injection. In confirmation of previous ideas these authors have shown how endosteal deposition on the metaphysis associated with periosteal resorption as part of the remodelling process of the funnel accounts for increase in length of the cylindrical shaft of the bone as the animal grows older without "interstitial growth of bone." ^{45}Ca has also been used in rats (Tomlin, Henry and Kon 1953). In these experiments rats thirty days old received a daily diet containing radioactive calcium. The growth of the femur and humerus was then studied by observing the position of the non-radioactive bone with respect to the radioactive bone at various time intervals after starting the diet. The results show how differences in deposition of new bone on the anterior and posterior walls are related to the curvatures of the bone cortex. Observations on the uptake of radioactive strontium in rabbits (Kidman *et al.* 1952, Jowsey *et al.* 1953*a*, Jowsey, Owen and Vaughan 1953*b*) and in pigs (Comar, Lotz and Boyd 1952) have shown that the sites of deposition of this isotope in the bones correspond with those of the formation of new bone tissue, and many new facts concerning its rate of uptake and position in animals of different ages have been recorded.

Previous work with the autoradiographic technique has been done using longitudinal sections of bone. There are, however, inherent limitations to the information which can be obtained in this way. In the present investigation, which is a study of the growth of the proximal half of the tibia of the rabbit, it was therefore decided to use transverse sections, making use of both microradiographic and microautoradiographic techniques. Microradiographs of transverse sections reveal structural features not evident under the ordinary microscope—in particular, variation in degrees of calcification in different areas of bone. For the preparation of the autoradiographs, ^{90}Sr, which emits β particles of maximum energy 0·53 mev and has a half-life of twenty-five years, was used as a tracer. The animals were injected with a single dose of carrier-free $^{90}SrCl_2$ solution and killed at various times after injection. A study of the position of the isotope incorporated at the time of injection was then made.

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EXPERIMENTS

Rabbits came from the same stock as before (Kidman *et al.* 1952). They were injected with a single dose of carrier-free $^{90}SrCl_2$ (about 800 μc per kilogram body weight). Table I gives details of the rabbits studied.

TABLE I

DETAILS OF RABBITS USED IN THE EXPERIMENTS

Age when injected	Time after injection when killed	Number of rabbits
5–7 weeks	1–3 days	3
5–7 weeks	8 weeks	2
5–7 weeks	6 months	2
6 months	1 day	1
6 months	17 days	1
6 months	6 months	1
10 months	1 day	1

A study of the uptake of ^{90}Sr was made in young and actively growing animals, five to seven weeks old (weanling), and in older animals of six months and older. Both microradiographs and autoradiographs were obtained of a series of transverse sections of the proximal half of the tibia-fibula, extending from just below the epiphysial plate to the middle of the shaft.

Microradiographs of corresponding sections from the tibia of rabbits which had received no isotope were also obtained for comparison. A list of these is given in Table II.

TABLE II

DETAILS OF RABBITS USED AS CONTROLS

Age of rabbit	Number of rabbits
5–7 weeks	3
3½ months	2
7 months	3
12 months	1

Techniques—The technique of cutting and grinding undecalcified sections of bone to a thickness of about 50 μ and of preparing both microradiographs and autoradiographs has already been described (Kidman *et al.* 1952, Jowsey, Owen and Vaughan 1953*b*). The sections which were cut and examined in series were numbered 1 to n, number 1 being at the middle of the shaft. Adjacent sections were about 0·5 millimetres apart.

RESULTS

MICRORADIOGRAPHS

A detailed account of the microradiographs of the non-radioactive rabbits is given which ensures that the characteristics to be described are in no way due to any effects from radioactive strontium. The general features of growth are most easily distinguishable in the rabbits five to seven weeks old and three and a half months old. There is slower growth in length after three and a half months, and the bone of the seven-month and twelve-month old rabbits is merely thicker

and more mature. Figure 1 is a diagrammatic model of the tibia-fibulae of rabbits of five to seven weeks, three and a half months, and seven months old. The numbers at the side correspond to the level from which particular cross-sections are taken.

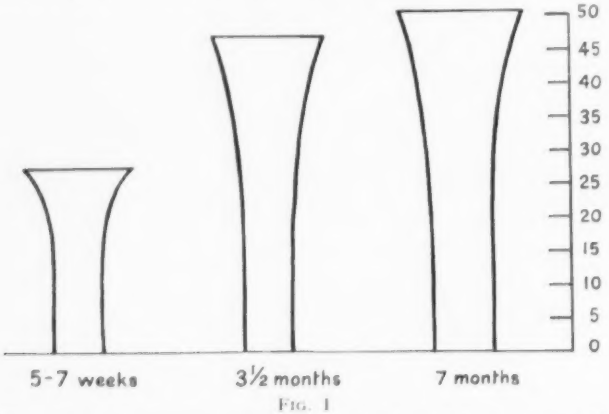

FIG. 1

Diagrammatic representation of the relative sizes of the proximal half of the tibiae-fibulae of rabbits aged five to seven weeks, three and a half months and seven months. Numbers at the side correspond to the positions of sections referred to in the text.

One of the most striking observations is the large number of remnants of highly calcified cartilage found throughout the length of the bone studied in animals of all ages. These cartilage remnants and the bone in which they are embedded are presumably the remains of

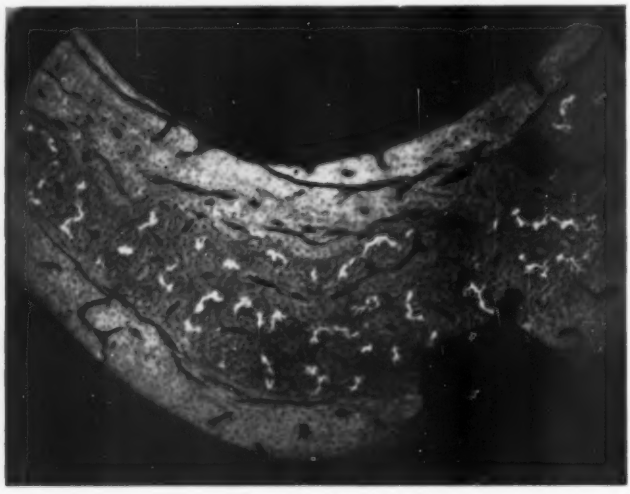

FIG. 2

Microradiograph showing highly calcified cartilage remnants in band of epiphysial bone. Part of section 15 from the tibia of a rabbit aged three and a half months. (×30.)

the epiphysial bone formed when the epiphysial plate was at this level (Jowsey, Owen and Vaughan 1955). Figure 2, taken from section 15 of the three and a half months old rabbit, shows part of the band of epiphysial bone remaining at this level. The highly calcified cartilage shows

up as white zig-zag lines; more recently formed non-Haversian bone can be seen on the periosteal and endosteal surfaces.

In sections taken in order from the mid-shaft towards the epiphysis the distribution of remnants of highly calcified cartilage presents a definite picture which varies little from one animal to another of the same age and only in degree amongst animals of different ages. A study of the distribution of these remnants in the sections shows how and where new bone has been formed during growth.

Serial cross-sections of the tibia of the rabbit aged five to seven weeks—Diagrammatic representations of these cross-sections are given in Figure 3. Some of the corresponding microradiographs are shown in Figures 4 to 8. In Figure 3 the position of the remains of epiphysial bone and areas of active deposition of bone on the periosteal and endosteal surfaces are marked.

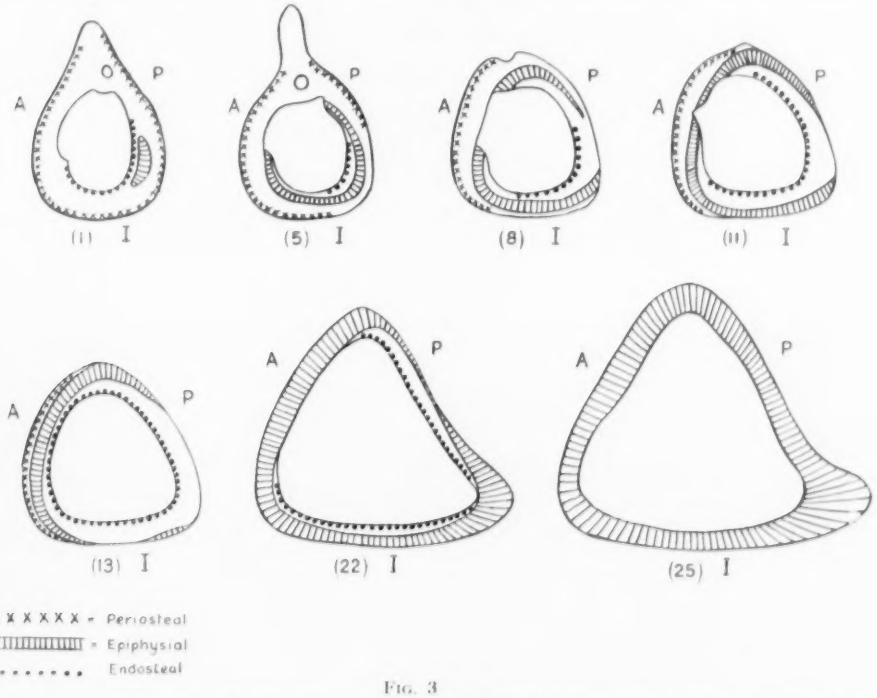

FIG. 3

Diagrammatic representations of the cross-sections of the tibia of a rabbit aged five to seven weeks. A = anterior wall; I = internal wall; P = posterior wall.

On the microradiographs of young rabbits these areas of deposition have a characteristic appearance. On the periosteal surface numerous capillaries are seen entering the bone, surrounded by areas with a low degree of calcification. On the endosteal surface the bone is trabecular and the surface is rendered irregular by marrow spaces around which calcification takes place. Examples of these are to be seen on the periosteal surface of the anterior wall and the lower half of the endosteal surface of the posterior wall (Fig. 5, section 8).

The uneven distribution of periosteal and endosteal bone formation is striking (Fig. 3). In the mid-shaft (section 1) there is periosteal growth practically all the way round and a few patches of endosteal deposition especially at the corner between the internal and posterior walls (hereafter called IP). In section 5 (Figs. 3 and 4) periosteal deposition predominates in the anterior wall and the band of epiphysial bone has been partly resorbed via the endosteal surface; there is also some deposition on the endosteal surface at IP. In sections 8 and 11 (Figs. 3 and 5)

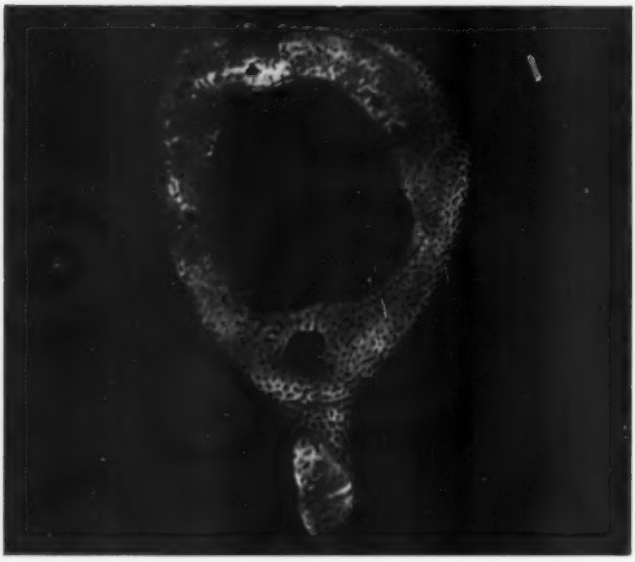

FIG. 4

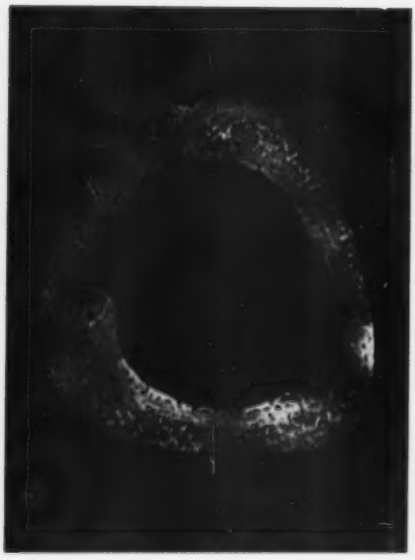

FIG. 5

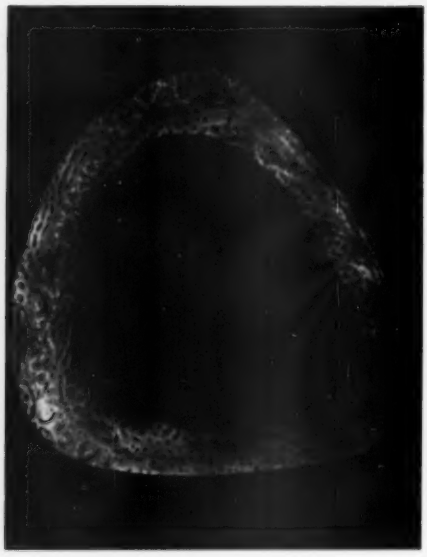

FIG. 6

Microradiographs of transverse sections of the tibia of a rabbit aged five to seven weeks. (All × 14.) Figure 4—Section 5. Note the vascular appearance typical of young actively growing bone on periosteal surface of anterior wall and endosteal surface at corner IP. Note also the remains of epiphysial bone in posterior and internal walls. Figure 5—Section 8. Note growth on the periosteal surface of the anterior wall and increasing growth on the endosteal surface at corner IP, and the position of the band of epiphysial bone indicating its resorption on endosteal surface of anterior wall and periosteal surfaces of posterior and internal walls. Figure 6—Section 13. Note the growth taking place on entire endosteal surface, and the band of epiphysial bone largely in anterior wall which also shows periosteal growth.

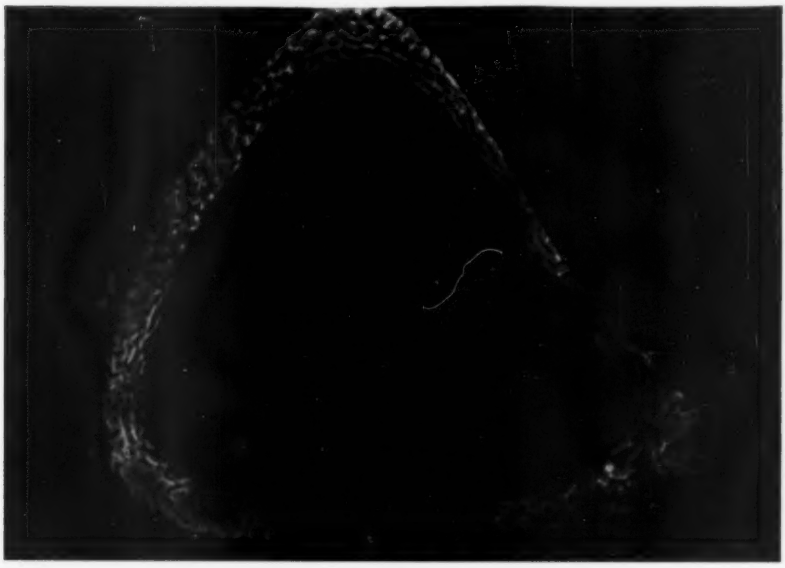

FIG. 7

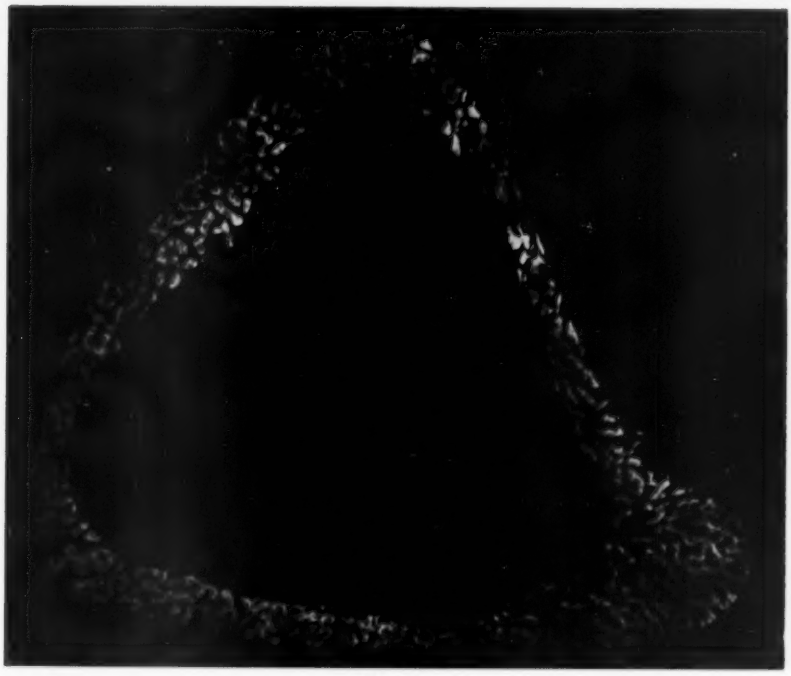

FIG. 8

Further sections from the rabbit's tibia shown in Figures 4 to 6. (× 14.) Figure 7—Section 22. Note the endochondral bone remaining in anterior wall, and epiphysial bone resorbed on periosteal surface of posterior and internal walls and replaced by endosteal bone. Figure 8—Section 25. Note the presence of epiphysial bone in all walls.

there is bone formation on the periosteal surface of the anterior wall with resorption on its endosteal surface; endosteal deposition now extends from IP along the surfaces of the posterior and internal walls while resorption takes place on the periosteal surfaces of these walls. In section 13 (Figs. 3 and 6) bone formation is taking place on the entire endosteal surface. Remnants of epiphysial bone now remain almost entirely in the anterior wall; and there is still evidence of periosteal deposition in this situation. Section 22 (Figs. 3 and 7) shows how the band of bone containing cartilage remnants—that is, bone formed in the region of the epiphysial plate, spoken of as epiphysial bone—remains in the anterior wall while it is quickly resorbed

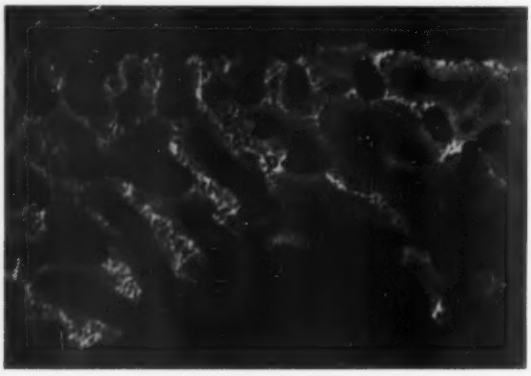

FIG. 9

Microradiograph showing epiphysial bone containing calcified cartilage and large cells. Part of corner between internal and posterior walls of section 26 of the tibia of a rabbit aged five to seven weeks. (×45.)

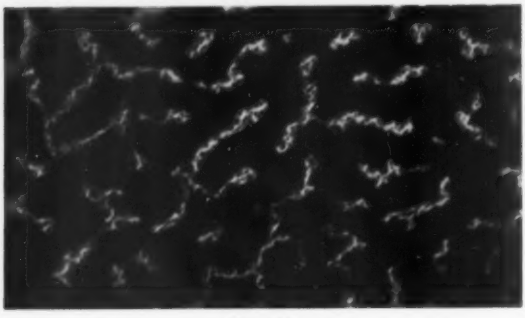

FIG. 10

Microradiograph showing epiphysial bone just below the epiphysial plate. Section 28 from the tibia of a rabbit aged five to seven weeks. (×45.)

via the periosteal surface on the posterior and internal walls and replaced by bone laid down on the endosteal surface. Section 25 (Figs. 3 and 8), which comes from just below the epiphysis, shows the presence of epiphysial bone equally in all three walls. Figure 9 illustrates detailed structure from corner IP in an adjacent section, and shows pieces of calcified cartilage containing large cartilage cells, embedded in new bone which has been formed adjacent to them. Figure 10 illustrates part of section 28, which is cut where the whole area of the cross-section is made up of epiphysial bone and demonstrates clearly that the bone adjacent to the calcified cartilage is less highly calcified than is this tissue.

Serial transverse sections of the tibia of rabbits three and a half, seven and twelve months old—In our experiments the mid-shaft was taken as the geometrical middle of the bone. It is therefore unlikely that the mid-shaft of the weanling and the older animals will correspond precisely, for it is known that the tibia does not grow equally from each end (Payton 1931–32, Bisgard and Bisgard 1935, Gill and Abbott 1942) and also no two animals grow exactly alike. In fact, sections from a particular level in the weanling as marked in Figure 1 should be compared with those of a slightly lower level in the older animals. Because of growth in width the junction of the tibia and fibula is relatively higher in the older rabbits than in the weanling. A comparison of the first twenty sections of the weanling with those of the older rabbits shows that the position of cartilage remains in comparable sections in rabbits from all ages is very similar. On the whole, there are fewer cartilage remnants in the bones of the older rabbits, many of them having already been removed in the process of remodelling. The bone of the

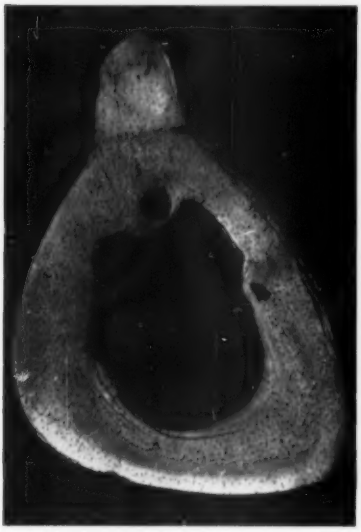

FIG. 11

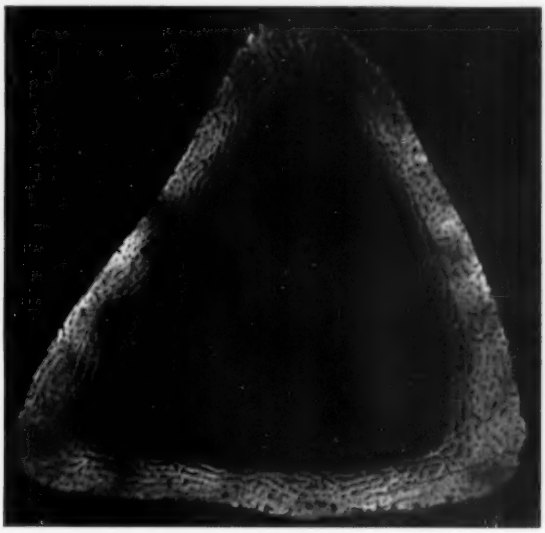

FIG. 12

Figure 11—Microradiograph of section 6 from the tibia of a rabbit aged seven months. Periosteal and endosteal bone is almost entirely non-Haversian. Note also the relatively low calcification of remains of epiphysial bone in internal wall. (×12.) Figure 12—Microradiograph of section 34 from the tibia of a rabbit aged three and a half months. Note the vascular appearance of endosteal surface typical of active growth, and the eaten appearance of periosteal surface where endochondral bone has been resorbed. (×12.)

seven months and twelve months old rabbits is very similar and it is only necessary to show examples and describe that of the seven months old. This older bone is much more mature than the bone of the weanling or of the three and a half months old rabbits which is in an intermediate stage. This maturity is demonstrated in many ways. For example, the bone is thicker, the Haversian systems and lacunae are smaller, giving it a more solid appearance, and it is more highly calcified. Moreover periosteal and endosteal bone is now almost entirely non-Haversian. An example is shown in section 6 (Fig. 11) of the seven months old rabbit. The position of the band of old bone containing cartilage remnants which is still present in the interior of the cortex in this section can be compared directly with that in section 8 (Figs. 3 and 5) of the weanling. Note also that the band of epiphysial bone in Figure 11 is of a lower degree of calcification than the more recent bone formed on the periosteal and endosteal surfaces. Higher up, in sections 14 to 23 approximately, remains of a band of epiphysial bone can be found in the anterior wall, but not in other walls at this level. This finding is in agreement with the results

FIG. 13

Microradiograph of section 47 from the tibia of a rabbit aged seven months. Note the band of endosteal bone, the remains of epiphysial bone on periosteal surface; and the cartilage remains in IP. (×14.)

FIG. 14

FIG. 15

Figure 14—Microradiograph showing epiphysial bone at corner between anterior and internal wall of section 42, from the tibia of a rabbit aged seven months. (×45.) Figure 15—Microradiograph of part of section 1 from the tibia of a rabbit aged five to seven weeks. Note periosteal bone containing small lacunae, and bone containing small evenly calcified Haversian systems among more highly calcified bone with large lacunae. (×40.)

obtained in the weanling rabbit and becomes of importance later when the autoradiographs are considered.

As can be seen from Figure 1, the first twenty sections comprise approximately the cylindrical part of the shaft of the adult animal. Above section 20—that is, during the period of growth of the metaphysial funnel or from the age of five to seven weeks onwards, transverse growth is of a different character. It is, in fact, practically pure apposition on the endosteal surface with resorption of the epiphysial bone on the periosteal surface. However, sections from just beneath the epiphysis show that deposition of bone during this period is also uneven, in that there is definite evidence that these processes are still more rapid on the surfaces of the posterior and internal walls than on those of the anterior wall. A typical example of endosteal deposition and periosteal resorption is seen in section 34 (Fig. 12) of the three and a half months

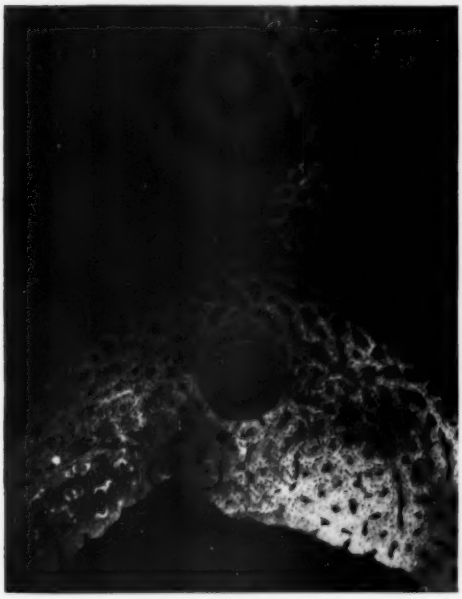

FIG. 16

FIG. 17

Figure 16—Microradiograph of junction of tibia and fibula. Section 6 from a rabbit aged five to seven weeks. Note the large lacuna in the bone at the junction. (×30.) Figure 17—Microradiograph of section 3 from the tibia of a rabbit aged three and a half months. Note area of resorption cavities and building sites remodelling band of old bone. (×17.)

old rabbit, which shows, especially at corner IP, numerous marrow spaces with a low degree of calcification on the endosteal surface, and an eaten appearance on the periosteal surface indicating resorption. Section 47 (Fig. 13) of the seven months old rabbit also shows a distinct band of endosteal bone and remains of epiphysial bone which are in the process of being resorbed on the periosteal surface. This section has the typical shape of the cross-section of the tibia of the adult animal at this level. Corner IP is extended and contains many pieces of cartilage, within which are embedded large cartilage cells similar to those shown in Figure 9. There is always some epiphysial bone at each of the other corners (Fig. 14). The bone adjacent to the calcified cartilage is of a lower degree of calcification than the calcified cartilage and the intervening Haversian systems.

Many other details may be observed on the microradiographs. It is seen that old bone (that is, bone formed early in the life of the animal) contains much larger lacunae than more

recently formed bone. For example, in sections from the mid-shaft of the weanling, such as that shown in Figure 15, the bone of the deep part of the cortex has large lacunae, while in the more recently formed bone on the outer surface these are smaller (Fig. 15). The origin of this band of bone with large lacunae is being further studied. Similar large lacunae are also seen in epiphysial bone, in particular in the lowly calcified bone which is adjacent to highly calcified cartilage (Fig. 14), and in many other places, particularly the junction of the tibia and fibula (Fig. 16). In all the examples noted very active bone formation was taking place at the time the bone was formed, and it is possible that the cells are larger for this reason. Remains of these large cells can be seen in seven months old and twelve months old bone. Compare, for example, the cells in the band of old bone in Figure 18 with those in more recently formed periosteal bone.

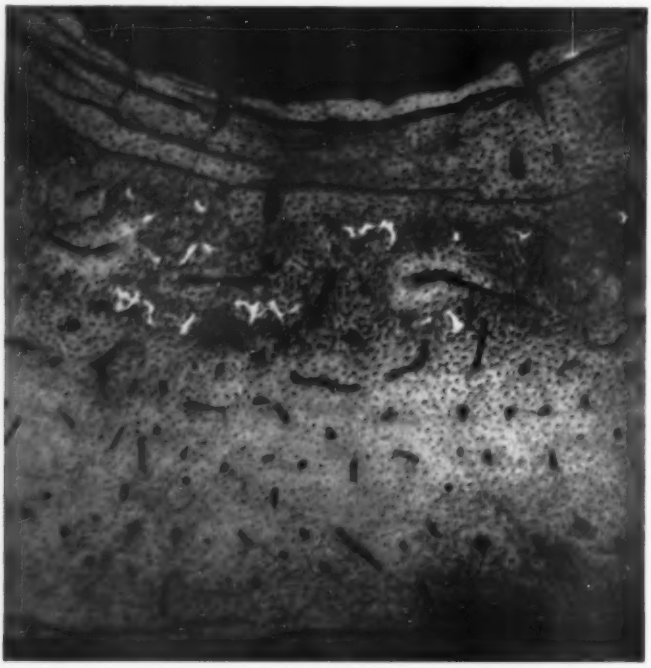

FIG. 18

Microradiograph of part of section 1 from the tibia of a rabbit aged seven months. Note highly calcified Haversian systems in region of epiphysial bone, and highly calcified periosteal bone. (× 85.)

There are a considerable number of resorption cavities and building sites in animals of all ages, illustrating the continual remodelling of bone. Resorption cavities, building sites and Haversian systems are closely related to one another anatomically and develop one from the other (Tomes and Morgan 1853, Petersen 1930, Amprino 1952, Jowsey *et al.* 1953*b*). In the microradiograph the typical resorption cavity appears as a large hole with an irregular boundary, the building site as a large or small hole with surrounding bone showing variable degrees of calcification and the Haversian system, which is a completed osteone, as a small hole with an even degree of calcification around it (Fig. 17). The distribution of resorption cavities and building sites was almost entirely associated with areas containing remains of calcified cartilage and old bone (Figs. 4 to 6). A typical example of this is the area of resorption cavities and building sites in the posterior wall (Fig. 17) demonstrating the removal and replacement of the band of old bone in the mid-shaft of this rabbit. The latter is characterised by the large

cells in the bone between the Haversian systems (see above). Figure 18 is another example of remodelling taken from the internal wall of section 1 of the seven months old rabbit. Note here the fully calcified new Haversian system, which is more highly calcified than the band of old bone in which it is situated.

AUTORADIOGRAPHS

Previous work on the deposition of radioactive strontium and calcium in bone, based on a study of autoradiographs prepared from both longitudinal and cross-sections, suggests that both isotopes are incorporated into areas of active bone formation (Kidman *et al.* 1952, Jowsey *et al.* 1953*b*, Lacroix 1953). The autoradiographs made from sections of bones of rabbits in the present series confirm both this hypothesis and the conclusions drawn from the microradiographs. The detailed results from three rabbits can be considered as representative of the findings in all the animals examined and included in Table I. Two of these were injected when weanlings and killed eight weeks and twenty-four weeks after injection. The third was injected when six months old and killed seventeen days after injection.

Rabbits injected as weanlings and killed eight weeks and six months after injection—The ^{90}Sr retained in the weanling killed eight weeks after injection showed a similar pattern to that retained in the weanling killed twenty-four weeks after injection.

Section 6 (Fig. 19) of the rabbit killed twenty-four weeks after injection shows the position in the shaft of ^{90}Sr taken up on the periosteal and endosteal surfaces at the weanling stage. It has exactly the position expected when compared directly with the microradiograph of section 8 of the weanling (Figs. 3 and 5). Of course, when the rabbit, from which the section shown in Figure 19 was taken, was a weanling, the tibia and fibula had not joined: if they had the band of periosteal uptake would have been different in position and would have appeared like that in Figure 20. The site of entry of the artery in section 8 (Fig. 3) in the centre of the band of periosteal growth corresponds to the position of the artery in the middle of the band of reaction in Figure 19. Further periosteal deposition results in junction with the fibula. A little farther up the shaft (section 11, Fig. 21) the autoradiograph shows a band of radioactivity corresponding to endosteal uptake. It is as expected when compared with section 13 of the weanling (Figs. 3 and 6). In the rabbits killed eight weeks after injection autoradiographs of some sections from this level show evidence of uptake on the periosteal surface of the anterior wall, which is also to be expected (see section 13, Figs. 3 and 6). There is also evidence that this is in the process of being resorbed and is thus not visible in rabbits killed six months after injection. Another example from this rabbit is section 1 which compares directly with section 1 of the weanling (see Fig. 20). In this section there are interesting examples of closed Haversian systems containing ^{90}Sr which are fully calcified in the microradiograph. These were presumably of low calcification at the time of injection.

Typical uptake on the endosteal surface has the appearance of a necklace because in the weanling the strontium was laid down round the large marrow spaces included by trabecular bone which were present at the time of injection (Fig. 22). Typical uptake on the periosteal surface also occurs in relation to the vascular supply, which in this case is dependent on periosteal capillaries and therefore presents a slightly different appearance (Fig. 23). This uptake occurring in relation to the blood vessels and sinuses on the periosteal and endosteal surfaces is typical of the young and actively growing rabbit. As will be seen later, uptake on these surfaces in the older rabbit is different.

The autoradiograph of section 20 (Fig. 24) of the weanling killed twenty-four weeks after injection shows a striking example of uptake in areas of highly calcified cartilage and the bone adjacent to it. At the time of injection this was presumably in the region of the epiphysial plate, which is known to take up strontium very readily in the weanling rabbit (Jowsey *et al.* 1953*a*). Tissue showing this type of uptake is only evident in the anterior wall, the epiphysial bone laid down in the posterior and internal walls having later been resorbed via the periosteal surface and replaced by bone laid down on the endosteal surface (section 22 of the weanling in

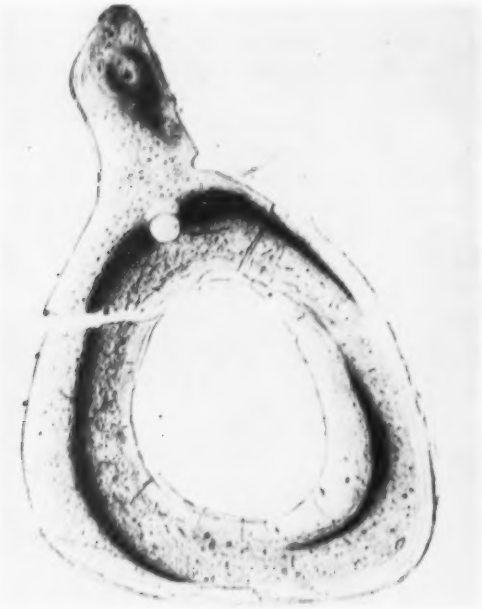

FIG. 19

Autoradiograph left on section of the tibia of a rabbit injected at five to seven weeks old and killed twenty-four weeks later. Note concentrated reaction in the remains of periosteal bone in the anterior wall and endosteal bone in the posterior wall. (×12.)

FIG. 20

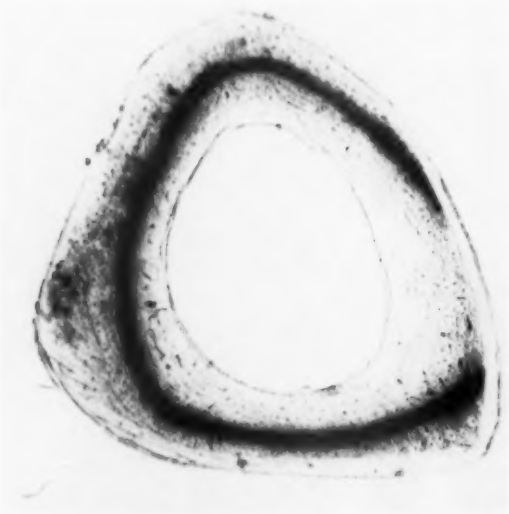

FIG. 21

Figure 20—Autoradiograph removed from section I of the tibia of a rabbit injected at five to seven weeks and killed eight weeks later. Note heavy reaction in remains of old periosteal bone, reaction in remains of endosteal bone, and reaction round the outer rings of fully formed Haversian sections. (×10.) Figure 21—Autoradiograph left on section II of the tibia of a rabbit injected five to seven weeks old and killed twenty-four weeks later. Note the concentrated reaction in the remains of old endosteal bone. (×12.)

Figs. 3 and 7). There is no significant ^{90}Sr uptake in sections above about level 20, presumably because this bone was formed after the ^{90}Sr level in the blood had fallen appreciably. For the same reason there is also no uptake in many Haversian systems which show low calcification on the microradiographs.

It should be mentioned that the bones of this rabbit grew much less after the weanling stage than the normal seven months old rabbit. This was due probably to the heavy deposit of radioactive Sr in the calcified cartilage of the weanling, for the microradiographs show some evidence of disorder in the bone formed above the weanling level. Further experiments are at present in progress to investigate these effects.

Rabbit injected at the age of six months and killed seventeen days after injection—Autoradiographs from certain sections show examples of the uptake of strontium in building sites which are seen to be lowly calcified on the microradiographs. These building sites are situated within the band of old bone which was formed early in the life of the animal. Old bone includes both the epiphysial bone which was laid down beneath the epiphysial plate and the

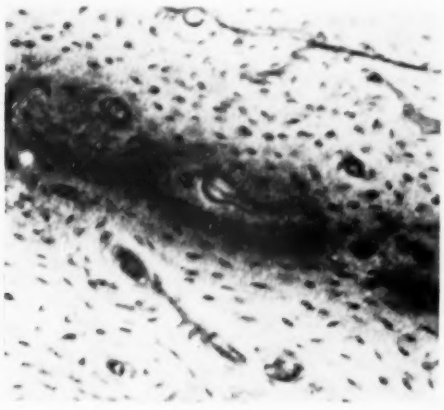

FIG. 22

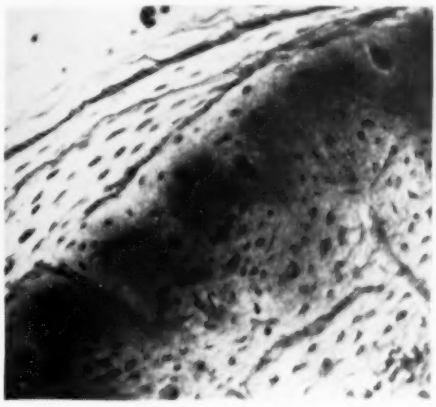

FIG. 23

Figure 22—Autoradiograph left on section, illustrating characteristic uptake of endosteal surface in actively growing tibia. Rabbit five to seven weeks old at time of injection, killed eight weeks later. Note the new bone laid down on that originally taking up ^{90}Sr. (×140.) Figure 23—Autoradiograph left on section, illustrating characteristic uptake on periosteal surface in actively growing tibia. Rabbit five to seven weeks old at time of injection, killed eight weeks later. Note the new bone laid down on that originally taking up ^{90}Sr. (×140.)

band of Haversian bone with large lacunae found in the mid-shaft. Figure 25, which is taken from level 8, is a good example of remodelling of the band of old bone in the anterior wall. It is comparable with about section 11 of the weanling (Fig. 3). Section 16 (Fig. 26) is an example of the remodelling of the calcified cartilage which has remained in the anterior wall at this level. There is little growth in width of the cylindrical part of the shaft at this age. There are only patches of uptake to be seen on the periosteal and endosteal surfaces. In the metaphysis there is still considerable uptake on the endosteal surface (section 40, Fig. 27). Detail from this section (Fig. 28) shows that the growth is non-haversian, which is characteristic of endosteal and periosteal growth in older animals. Uptake in calcifying cartilage at corner IP also occurs (Fig. 27).

DISCUSSION

The facts recorded here may be discussed under two headings, one concerned with the details of tibial growth in the rabbit, the other with the relevance of the observations to general problems of bone growth and pathology.

Bone growth in the upper half of the tibia—Some interesting features concerning the growth

of the proximal half of the tibia have been observed. The growth in length of the bone occurs at the epiphysial plate by the normal process of endochondral ossification. More by chance than design the tibia at five to seven weeks old was studied and the length of the tibia at this age is approximately the length of the cylindrical part of the shaft of the adult rabbit. The transverse growth of this part occurs by the apposition of bone on both the periosteal and endosteal surfaces in a characteristically uneven manner which has approximately the same pattern throughout the period up to seven months. This also results in the retention of epiphysial bone within part of the walls at various levels. The transverse growth of the metaphysial funnel occurs by apposition of bone on the endosteal surface and resorption of the epiphysial bone on the periosteal surface. These processes are also uneven, in that they take place more rapidly on the surfaces of the posterior and internal walls than on those of the anterior wall.

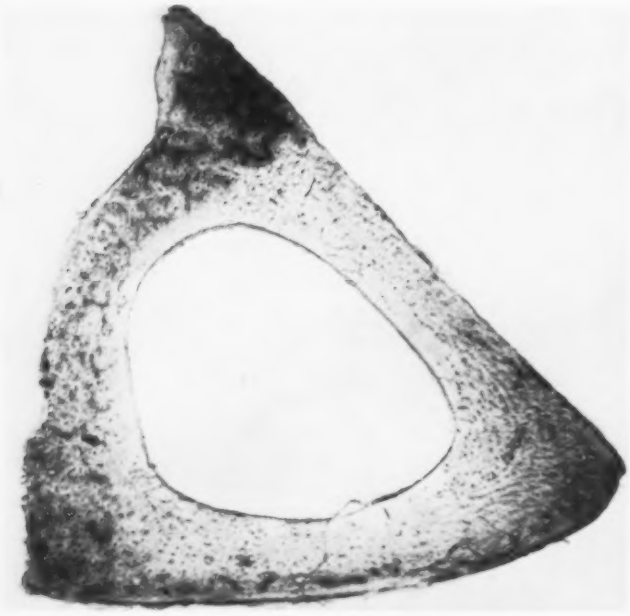

FIG. 24

Autoradiograph left on section 20 of the tibia of a rabbit injected at five to seven weeks and killed twenty-four weeks later. Note the heavy reaction in the epiphysial bone in the anterior wall, particularly in remnants of calcified cartilage. (×12.)

This uneven growth on different walls was first noted by Duhamel (1743) using the madder technique.

The results described can be presented diagrammatically (Fig. 29). The Figure represents a longitudinal section through the middle of the anterior and posterior walls and demonstrates growth before seven months. The heavy broken lines show the position of the calcified cartilage remnants in the walls. A careful comparison of this with a previous macroscopic autoradiograph of a similar longitudinal section of the tibia of a rabbit injected as a weanling and killed six months later (Fig. 30) (Jowsey *et al.* 1953*a*) shows that the present results are in entire agreement with this work and provides a clear explanation of the localisation of ^{90}Sr shown on this autoradiograph. The heavy deposition at (*x*) in the anterior wall is mainly due to the retention of the strontium in the calcified cartilage of epiphysial bone which was being formed at the time of injection (Fig. 24). As seen earlier, epiphysial bone is retained in this wall while it is

FIG. 25

FIG. 26

Figure 25—Autoradiograph left on section 8 from the tibia of a rabbit injected when six months old and killed seventeen days later. Note the heavy reaction round building sites in the anterior wall. (×11.)
Figure 26—Autoradiograph left on section 16 from the tibia of a rabbit injected when six months old and killed seventeen days later. Note the heavy reaction around building sites in the anterior wall, and traces of reaction in patches of periosteal bone. (×11.)

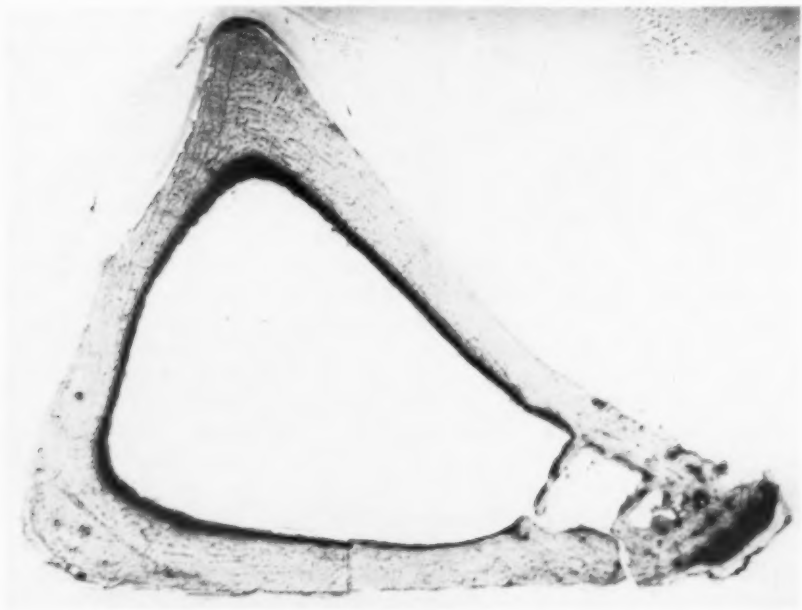

FIG. 27

Autoradiograph left on section 40 from the tibia of a rabbit injected when six months old and killed seventeen days later. Note the heavy reaction in endosteal bone and in calcifying cartilage at IP. (×11.)

quickly resorbed from the posterior and internal walls at this level (section 22 of weanling, Figs. 3 and 4). At *y* the anterior wall shows lines of uptake on both periosteal and endosteal surfaces (compare with section 13 of weanling, Figs. 3 and 4). The patches between the endosteal and periosteal lines are probably due to uptake in building sites which are known to be remodelling epiphysial bone even in young rabbits. At *y* in the posterior wall there is a line of endosteal uptake which ends abruptly. This is because endosteal deposition is rapid on this wall, especially higher up where endosteal bone laid down when the animal was a weanling has been resorbed via the periosteal surface six months later. (See section 11 of the rabbit injected as a weanling killed six months later, Fig. 20, which is comparable with about level 15 of the weanling.) At *z* there is very active deposition on the periosteal surface of the anterior wall, and lines of endosteal and periosteal growth on the posterior wall with remodelling of the epiphysial bone retained between them (compare with section 5 of the weanling, Figs. 3 and 4).

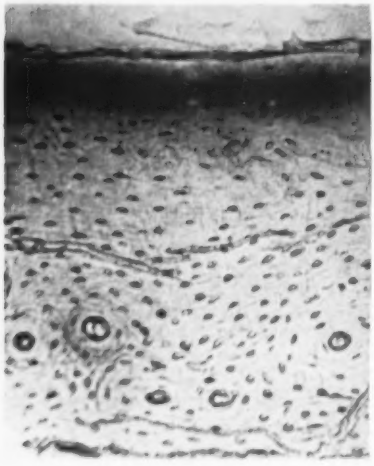

FIG. 28

Autoradiograph illustrating characteristic uptake on periosteal surfaces of tibia in rabbit six months old at time of injection, killed three weeks later. (× 140.)

It is clear from Figure 29 that the axis of growth is slightly displaced from the bone axis. This is because the tibia is not symmetrical about its longitudinal axis. It is in fact flatter and less curved on its anterior wall. This difference between the growth axis and the bone axis which is due to the unique shape of the tibia accounts for the unevenness of transverse growth in both the shaft and the funnel.

These results are in agreement with the general principle of transverse growth, namely endosteal apposition in the metaphysis and periosteal apposition in the shaft. They also demonstrate in which region of the adult rabbit tibia remnants of highly calcified cartilage may be found. Animals injected when the epiphysis is at a particular level will incorporate ^{90}Sr in the calcifying cartilage which remains at this level and retains it for a long time. The existence of resorption cavities and building sites which might have been expected from theoretical considerations of bone remodelling has been recognised before, but the present work demonstrates their situation and the contribution they make to the changing structure of developing and adult bone.

Relevance to general bone growth and pathology—The extremely variable pattern of bone structure within one long bone, depending both upon age and the anatomical level at which the bone is examined, has already been emphasised by Amprino and Bairati (1936) in the case of the human femur, and is well illustrated by the preceding observations in the tibia of the rabbit. On the other hand the similarity of the picture seen at any one anatomical level of the tibia in animals of the same age was striking. It is thus clear that in assessing the abnormality of bone structure in pathological material it is necessary to compare sections with those taken at the same anatomical levels from control normal animals of the same age and species. Individual pathological specimens must be interpreted with caution and the findings in one species or in one bone cannot be transferred to a different one.

Previous papers on the uptake of radioactive strontium (Kidman *et al.* 1952, Jowsey *et al.* 1953*a*, 1953*b*) have emphasised that this occurs almost entirely in areas of active bone formation. This finding is confirmed by the more detailed histological studies described here. An area of bone which once incorporated ^{90}Sr in concentration retains that ^{90}Sr unless it is removed by resorption in the normal process of bone growth and remodelling. The real hazard of ingested radioactive strontium in bone is dependent on its localised concentration. The possible part

played by a diffuse uptake throughout the bone dependent probably upon ionic exchange on the appetite crystal surfaces (Neuman and Weikel 1954), though of extreme interest from the point of view of general mineral metabolism, is probably not of importance so far as radiation hazards are concerned.

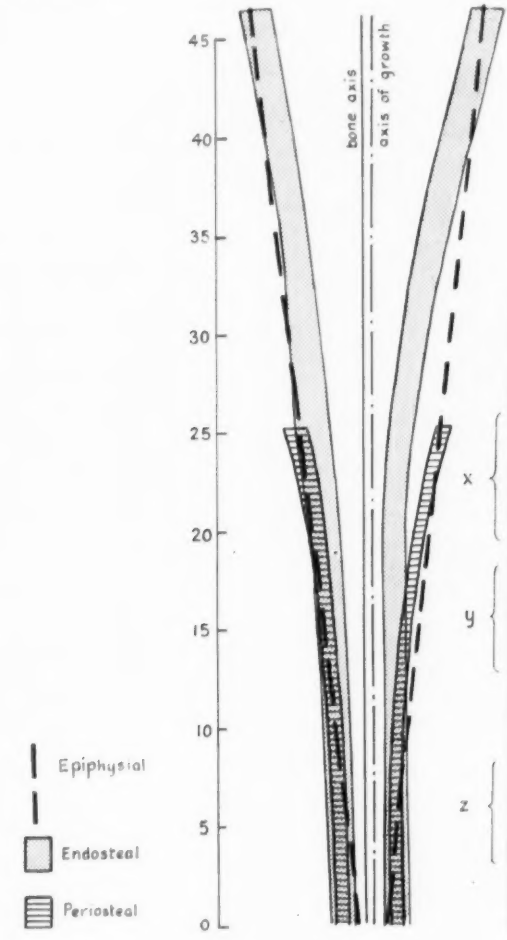

FIG. 29 FIG. 30

Figure 29—Diagrammatic representation of growth of proximal half of rabbit tibia during the period weanling to seven months. Longitudinal section. Figure 30—Autoradiograph prepared from longitudinal section showing retention of radioactive strontium in similar section of a rabbit tibia injected as weanling and killed six months later.

SUMMARY

1. The detailed anatomy and calcification of the upper half of the tibia in rabbits varying in age from six weeks to twelve months has been studied.

2. The structure of the bone varies at different levels, but a section taken from the same level in the tibia from animals of the same age presents a reasonably constant picture.

3. It has been shown that this variation in structure at different levels is directly related to a

difference between the axis of growth and the bone axis. This difference is a result of the unique shape of the tibia.

4. Autoradiographic studies confirm the localised concentration of radioactive strontium in areas of active bone formation where uptake is rapid.

5. The long retention of radioactive strontium in the skeleton (that is, the slow turnover) is a result of the slowness of resorption of bone (endosteal, periosteal or Haversian) in the cortex. Not only is the process slow but it is extremely localised.

6. The significance of these anatomical and physiological characteristics in relation to radiation injury is discussed.

This work was begun on behalf of the Protection Sub-Committee of the Medical Research Council's Committee on Medical and Biological Applications of Nuclear Physics.

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WILLEM NOORDENBOS

1875-1954

By the death of Emeritus Professor Willem Noordenbos of Amsterdam on August 18, 1954, at the age of seventy-nine, there passed one of the most notable figures in Dutch and international surgery.

Noordenbos's choice of medicine as a career was almost inevitable as he came from a long line of physicians. He graduated at Groningen University in 1904. During three of his undergraduate years he worked as an assistant in the anatomy department, and thereby acquired the minute and comprehensive knowledge of that subject which was apparent in all his surgery, especially in relation to incisions and approaches.

Soon after graduation he was appointed assistant to Professor Koch at the University Surgical Clinic. In 1908 he became lecturer in " Wound Dressing and Operative Surgery " at Utrecht, where later he was offered, but declined, the Chair of Anatomy. In 1913 he was appointed surgeon to the well equipped Coolsingel Hospital at Rotterdam. Here with a large number of beds under his charge, and an unlimited clientele, his opportunity came, and well he exploited it. His genius bourgeoned. There were few fields of general surgery which he did not explore, and fewer still to which he did not contribute substantially. In orthopaedic

surgery his chief work was on the traumatic side. Autogenous bone grafting became a great interest. Among other procedures, he evolved the operation of blind "pegging" of the fractured femoral neck with a segment of the fibula from the same leg. Three months in plaster, and three months thereafter in bed with non-weight-bearing exercises, produced in his hundreds of cases results which were infinitely superior to those obtained by any other method in vogue at that time and, indeed, they could stand comparison with the results of the more facile methods practised to-day.

In 1920 he was installed in the Chair of Surgery at Amsterdam. The hospital lacked many of the facilities which he had enjoyed previously, but under his inspired leadership soon began to acquire, and justly, a reputation that was world-wide. Years of productive work followed—and then came the second world war. In May 1940, when the Germans entered Holland, his wards were occupied by a German Military Surgical Group. For some months he was allowed to carry on in a minor unit, but in October 1940 he was taken as a hostage, with several hundred other prominent Dutch citizens, to the concentration camp at Buchenwald. He was sent back on account of his age in April 1941, but two months later was discharged from his Chair of Surgery by the German authorities, and was not permitted to enter his hospital.

After the liberation he was reinstated and held office until his retirement in 1946.

During his occupancy of the Chair, the outstanding value of Noordenbos's work was recognised by many scientific associations and learned bodies. Among others, he was made an Honorary Fellow of the Association of Surgeons of Great Britain and Ireland, Honorary Member of the British Orthopaedic Association, Honorary Member of the Royal Society of Medicine, and Honorary Fellow of the Royal College of Surgeons of England.

As an operator, Noordenbos was dexterous, swift, unruffled and without elaborations. As a lecturer he was lucid, logical and never ponderous, and his publications exhibited the same qualities. As a chief, he enjoyed the confidence and inspired the efforts of his staff.

The search for truth in surgery was the ruling interest of his life, and he retained it after his retirement even during the prolonged illness which preceded his death.

Professor Noordenbos is survived by his wife, two daughters, and a son, a graduate of Edinburgh University, who practises as a neuro-surgeon in Amsterdam.

These factual lines, however, do not bring to mind Professor Noordenbos as he appeared to visitors at his clinic, which by the late 'twenties had become a veritable surgical Mecca. Visitors came in their hundreds from all corners of the globe and, whether they were giants in the surgical world or mere aspirants in the lower stratum, they were met with the same courtesy and kindness. He made them feel they were really welcome, and he usually greeted them in their own language. However long their sojourn might be, it appeared short. In the harmonious atmosphere of the operating theatre or in the happy wards Noordenbos would patiently explain what he was doing and why. New ideas were eagerly received, but were measured against the yardstick of experience and fundamental principles. Only a Boeotian soul could fail to be impressed by this great man who combined the enthusiasm of the student with the serenity that alone comes with deep knowledge.

He exemplified the dignity and humanity of man; he added to our knowledge. His memory is an inspiration and invokes, in those who knew him, a sense of gratitude.

R. I. S.

PROCEEDINGS AND REPORTS OF UNIVERSITIES, COLLEGES, COUNCILS AND ASSOCIATIONS

GREAT BRITAIN

UNIVERSITY OF LONDON

BRITISH POSTGRADUATE MEDICAL FEDERATION

Radiation effects on Bone—*Dr Janet Vaughan* lectured on this subject on January 25, 1955, in the series of lectures on the Scientific Basis of Medicine arranged by the British Postgraduate Medical Federation. Confining her observations to man, she divided radiation effects into osteodysplastic and osteoneoplastic. She further subdivided osteodysplastic changes into retardation of growth, fracture and osteomyelitis.

Osteodysplastic changes—Retardation of growth might be manifest by a line of increased density parallel to the growth plate, gross irregularity of the vertebral epiphysial cartilage plates, scoliosis, benign hyperostosis, and great shortening of long bones with thinning of the cortex. Fractures were commonest in women, involving the femur and the pelvis in 0·1 to 3·2 per cent of cases of prophylactic pelvic irradiation; they seldom occurred after irradiation of the genital organs in men. The fractures, which were not a manifestation of metastasis or of senile osteoporosis, occurred without injury and were characterised by a long latent period. Many bilateral fractures, not necessarily occurring simulatneously, were recorded. They often healed soundly. The susceptibility of irradiated bone to infection was often seen in the jaw.

Osteoneoplastic changes—Dr Vaughan classified irradiation into external, with x-rays for instance, or internal, as by the ingestion of radium or mesothorium. After external irradiation, thirty-nine instances of bone sarcoma were known to have occurred, always with a long latent period; for instance, sarcoma had occurred eleven years after irradiation of a tuberculous knee. The critical dose was probably not less than 3,000 R. The effects of internal irradiation were seen in the radium dial painters. The early victims died with blood dyscrasias and bone necrosis, the later ones with bone tumours. In the latter group, with a body burden as low as 0·7 μg., the latent period might be as long as thirty-two years.

Radiological evidence of bone injury included: coarsening of trabeculae; a mottled, "moth-eaten" appearance with complete destruction of normal bone pattern; longitudinal areas of increased and diminished density; small well defined areas of diminished density, especially in the skull, which were like those seen in multiple myelomatosis; fractures; and, in the young, bony fusion across the epiphysial plate.

Pathological changes—There was gross disorganisation of the normal bone pattern with both necrosis and atypical new bone formation, fibrosis and loss of metachromatic staining and thickening of the periosteum in the case of external irradiation. Chondroblasts were probably most sensitive and osteoclasts least. It was uncertain whether the primary damage was to the cells themselves or to vascular tissues. The characteristics of bone that made it specially susceptible were its heterogeneous structure, its affinity for many elements, its method of growth, and possibly the extensive crystalline surface of apatite. Elements chemically related to calcium, such as radium and strontium, were concentrated entirely in areas of active bone growth. There was no physiological explanation for the concentration of the other large group of "bone seeking" elements such as plutonium and yttrium. It could only be said that they followed a constant pattern. All radioactive elements appeared to be retained in bone in high concentrations of irregular distribution. A measure of total retention in the skeleton was therefore no measure of radiation risk. Uptake was rapid, but removal, at least of many elements, depended upon the normal process of bone remodelling and was therefore very slow.

Prevention and diagnosis—In conclusion, Dr Vaughan suggested: that external irradiation for non-malignant conditions should be confined to the elderly; that long-lived radioactive isotopes should not be given for therapeutic or research purposes; that it would be helpful if a personal record could be kept of all irradiation, both diagnostic and therapeutic, received by every individual during his lifetime; and that the possibility of irradiation damage should be considered in investigating any obscure chronic disease with affection of blood or bone, or especially both.

UNIVERSITY OF OXFORD

NUFFIELD ORTHOPAEDIC CENTRE

On January 4, 1955, the unveiling of oil portraits of Viscount Nuffield and the late G. R. Girdlestone took place in the Nuffield Orthopaedic Centre. It was a fitting act of recognition to

the two great personalities to whom the Wingfield-Morris Orthopaedic Hospital, its eighteen subsidiary clinics and the Nuffield Orthopaedic Centre owe their existence.

The Vice-Chancellor of Oxford University, Mr A. H. Smith, opened the proceedings, stressing the meaning of the ceremony and emphasising his life-long admiration for G. R. Girdlestone who had been a Fellow of New College of which he is the head. He then invited Sir Robert McCarrison, Chairman of the Postgraduate Medical Education Committee and an old associate of Girdlestone in the management of the Wingfield-Morris Orthopaedic Hospital, to read his eulogy on G. R. G. Sir Robert referred to his faith, humility and selflessness, to his kindness and generosity, and to the sense of mission which characterised the life and work of the great orthopaedic surgeon. He referred to the training and early medical life of G. R. G. under the guidance of Sir Robert Jones until the day in 1916 on which the basis of what is now the Nuffield Orthopaedic Centre was established. He rapidly enumerated the many steps in its development from the day when " that great benefactor of mankind, Lord Nuffield, then Sir William Morris, provided the large sum of money needed to replace the dilapidated huts by well designed and permanent buildings." He referred to the way in which Girdlestone imbued the hospital with his spirit of service, friendship and happiness which to this day permeates its wards, theatres and workshops.

The Vice-Chancellor then unveiled the beautiful oil portrait by Frank Eastman which had been purchased by donations from a large number of Girdlestone's grateful patients.

The Vice-Chancellor then called on Mr John Thompson to read his eulogy on Lord Nuffield. Referring to the enormous contribution to alleviate the suffering of mankind made throughout the whole of his life by Lord Nuffield, Mr Thompson said that he did not wish to enlarge on the many achievements such as the Nuffield Foundation, the Nuffield Provincial Hospitals Trust, Nuffield College and the Nuffield Institute, but he was on this occasion particularly interested in stressing the part that Lord Nuffield's contribution had played in the development of what had been only the Wingfield Convalescent Home into the prosperous and reputed Nuffield Orthopaedic Centre whose hospital bears Lord Nuffield's family name of Morris.

Professor J. Trueta, the present holder of the Nuffield Orthopaedic Chair, was then called upon to unveil Lord Nuffield's portrait which had been painted by John Wheatley and graciously presented by Lady Nuffield at the request of the Trustees of the Nuffield Orthopaedic Centre. Professor Trueta stressed the inspiration that all the workers in the hospital had received from his outstanding personality. He said he thought he could speak in the name of thousands of sufferers who had been helped to recovery in the institution created by the happy association of a surgeon and a philanthropist. In his own name and in that of his colleagues he rejoiced in the fact that from now on the portraits of Lord Nuffield and G. R. G. would preside over the heads of their followers in the room where all the important decisions for the future of the Nuffield Orthopaedic Centre and hospital are taken.

The ceremony was attended by members of the University, personal friends and admirers of the two honoured gentlemen, members of the hospital and a number of old patients who contributed to G. R. G.'s portrait.

VISIT OF BRITISH COMMONWEALTH TRAVELLING FELLOWS TO THE UNITED STATES AND CANADA

Mr H. J. Richards writes: On April 22, 1954, the Home Countries contingent of the British and Commonwealth Travelling Fellows sailed from Southampton on the *Queen Mary* for America. It was a gloriously sunny day as we took our farewell of Southampton, encouraged by telegrams of good wishes from the president of the British Orthopaedic Association and a number of other orthopaedic surgeons.

The trip across was a delightful one, if rather hectic, as our presence on board ship had been signalled to the ship's company and, although we were travelling " down among the pit ponies " (Tourist Class) we had the run of the ship. The trip also gave us the opportunity of getting to know each other.

The tempo of our life was disturbed by our arrival in New York and we were rapidly whisked through the maddening traffic by an intrepid taxi driver to the Columbia University Club, where we found our Australian colleague awaiting us. The old-world atmosphere of this Club was shattered by the arrival of Tommy Thomson and Ramsay Straub, who greeted us with great enthusiasm and cordiality and proceeded to entertain us in typical American fashion while, at the same time, they mapped out our vigorous New York programme.

We visited the teaching centres, a Veterans' hospital, a city hospital, a fashionable physical medicine centre, and some children's country rehabilitation hospitals. The social side was quite overwhelming and two novel events were a flight over New York in Dr Boswell's plane, during the

course of which we wondered whether there might not be some vacancies for orthopaedic surgeons either in Australia or Great Britain, and also a dinner party given in the Century Club by Dr Stinchfield. From New York we travelled to Wilmington, where Dr A. Shands took charge of us and arranged for us to stay at the Alfred I. Du Pont Institute of the Nemours Foundation, which has orthopaedic beds for children and admirable research facilities and must surely be the most luxurious and well run of its type. From here, we were able to visit the hospitals in Philadelphia and also to spend one day at Atlantic City, where we visited the Children's Seashore House Hospital and attended a meeting of the New Jersey Orthopaedic Society. Philadelphia we found to be a very active and progressive orthopaedic centre.

We went from Wilmington to Washington, where we spent what might be termed a long week-end, during which we were able to visit the hospitals and also did a great deal of sightseeing. We were entertained in a manner which one would expect in a capital city.

J. N. Wilson, H. R. T. Hodgkinson, G. P. Mitchell, D. M. Brooks, H. J. Richards.

We left Washington for Baltimore and, arriving there in the evening, we were immediately taken to a meeting of the Baltimore Orthopaedic Group where one of our party gave a short paper. We took the opportunity of visiting most of the orthopaedic centres and we were particularly struck by the use which was being made of the clinical and laboratory facilities and by the close co-operation which existed between the various departments of the Johns Hopkins Hospital.

Thence we flew to Montreal and arrived there in what might be described as typical British weather—low cloud and a mist and, later, some rain. We were met by Dr Petrie and Dr Favereux and received a very generous Canadian welcome. That evening we had an opportunity of seeing Montreal, which has an atmosphere of its own and was quite different from anything which we had, up to that time, encountered. On the following day we motored to Quebec through lovely country and were shown around this beautiful city by Dr Roy and his colleagues. On returning to Montreal we visited the orthopaedic centres there and also had the opportunity of attending a meeting of the Association of Orthopaedics and Traumatology of the Province of Quebec. In Montreal we found the mood towards orthopaedics to be virile and progressive and we were very sorry to leave this lovely city with its cosmopolitan atmosphere and take the night train to Toronto.

At Toronto we were met by Herb Coleman and Ian MacNab and were later under the wing of Dr R. I. Harris, who had arranged a heavy, but extremely interesting, orthopaedic and social programme. We found here a very enthusiastic approach to orthopaedics and research in this field, both clinical and experimental, nobody being more active than Dr Harris himself. From Toronto we made a memorable trip to Niagara Falls. On leaving Toronto, we travelled by car with the Toronto contingent to Bretton Woods for the meeting of the American Orthopaedic Association.

At Bretton Woods all delegates, including ourselves, stayed at the Mount Washington Hotel which is situated in the beautiful White Mountains in New Hampshire. Here we met many old friends and also the British contingent which included Professor and Mrs Mercer, Mr A. Malkin and Mr J. C. Scott, who were there for the meeting. The meeting was thoroughly enjoyable and was composed of just the right mixture of work and leisure. One of our party read a paper at the

meeting. At Bretton Woods we were able to make new as well as meet old acquaintances and to obtain many lasting memories in the form of photographs. The four days passed all too rapidly and we then motored to Boston.

At Boston we stayed at the Harvard University Club, and the atmosphere of this city was not unlike that of some of our own university cities. We had the opportunity of visiting all the major orthopaedic centres and were struck by the enquiring approach to all orthopaedic problems. One week-end was spent at Cod Bay, where we were introduced to a typical New England "Clambake."

We left Boston in rather a dejected mood, knowing that the trip was almost over, and we all hoped that we might return again to America and Canada, where we had seen and learned so much and had made so many friends. We regretted very much that we could not travel more widely in both countries and see the Western parts and meet the orthopaedic surgeons in those regions. We had met a few orthopaedic surgeons from those parts at the American Orthopaedic Association meeting and in New York and they had whetted our appetite.

Our impressions were that there was not a great deal of difference in the basic approach to orthopaedics in America, Canada and Great Britain. The methods of treatment differed in some respects, particularly with regard to tuberculosis of the spine, where the emphasis was on early fusion. In some centres there was a radical approach to the treatment of fractures, but not more radical than one might find in a few centres in Great Britain. There appeared to be greater facilities for research and a great deal more of it going on in all the centres we visited. The training period for an orthopaedic surgeon did not appear to be so long or so rigorous as in Great Britain, but the trainees appeared to have a more intimate knowledge of the patients than their opposites here—chiefly, I believe, because the standard of nursing was not so high as in this country. There appeared also to be a greater awareness of the legal aspect of medicine in America and Canada, and this was well put in a jocular manner by an American orthopaedic surgeon who said: "the operation which is least likely to lead to litigation is the one usually carried out and this may possibly not be the one which is best for the patient."

In conclusion, I think we all learnt a great deal about orthopaedics and also about America and Canada. It also gave us the opportunity to meet many famous orthopaedic surgeons and many more young, promising surgeons. We were also able to see the hospitals where orthopaedic surgery was carried out and were able to assess the work carried on there and, in the future, to assess, in the light of this experience, any publications which may come out from these Centres.

We should like to thank all those who were responsible for the organisation of this very successful trip, and are grateful to all those surgeons and their charming wives who entertained us so generously and enthusiastically while we were with them. We look forward to the opportunity of being able to return this hospitality to the American and Canadian Fellows who are visiting this country during the coming year.

THE ROBERT JONES AND AGNES HUNT ORTHOPAEDIC HOSPITAL, OSWESTRY

APPOINTMENT OF DIRECTOR OF CLINICAL STUDIES AND RESEARCH

Mr Robert Roaf has been appointed Director of Clinical Studies and Research at the Robert Jones and Agnes Hunt Orthopaedic Hospital, Oswestry. He will take up his duties in this post, of which he is the first occupant, in June 1955.

Mr Roaf was educated at Winchester, at Oxford and at Liverpool. He graduated in Medicine in 1938, obtained the F.R.C.S. (Edinburgh) in 1939 and the English F.R.C.S. in 1942. He became M.Ch.Orth. (Liverpool) in 1946. He is at present a consultant orthopaedic surgeon on the staff of the Robert Jones and Agnes Hunt Orthopaedic Hospital and of the Liverpool Royal Infirmary. He recently spent nearly two years advising on the establishment of orthopaedic clinics in India, when he worked in Delhi and in other centres. His many contributions to orthopaedic literature have been mainly concerned with peripheral nerve injuries, tuberculosis of bone and joint and the surgery of the hip.

SCIENTIFIC SOCIETIES AND REGIONAL ORTHOPAEDIC CLUBS

THE BONE AND TOOTH SOCIETY

The Bone and Tooth Society held a symposium on "Fluorosis" at the Institute of Orthopaedics, Great Portland Street, London, on January 20, 1955. Dr R. Nassim was in the chair.

Effects of fluorine on renal function and gastric secretion—*Professor M. M. Murray* showed that whereas it takes some time for fluoride to cause demonstrable changes in dental and skeletal structures, its effects on kidney function and gastric secretion are immediate. Kidney function

was influenced by a relatively low intake in experimental animals. Tubular function in particular was affected; diminished reabsorption of water and glucose produced polyuria and glycosuria. The distribution of alkaline phosphatase was markedly altered. After prolonged administration, the structure of the kidney tubules showed obvious changes. Chronic intoxication led to a vascular and tubular degeneration and interstitial fibrosis, with a loss of functional tissue. Introduction of low concentrations (0·005 *M* = 210 p.p.m.) of NaF into the stomach of cats inhibited the secretion of acid in response to histamine injection; this effect was reversible. It was suggested that these actions of fluoride depended on its inhibitory effect on enzyme systems associated with the energy exchanges required for the active transfer mechanisms of tubular reabsorption and gastric acid secretion.

Addition of fluoride to domestic water supplies in the control of dental caries—*Professor H. H. Stones* said that in districts where there was endemic fluorosis from fluoride in the water supply there was a comparatively low incidence of dental caries, both in children and adults. In 1945 controlled addition of fluorides to water supplies was started in three study centres in the northern part of U.S.A. and Canada, and by 1948 there were eight. The fluoride concentration used in practically all centres varied from 1 to 1·2 p.p.m. The compounds used were usually sodium fluoride or silicofluoride. The subjects for the study were children from five to fifteen years of age, and the duration had been planned to extend over ten to fifteen years. The results of the studies started in 1945 for the youngest subjects now showed a reduction of about 50 per cent in the incidence of dental caries. The best concentration of fluoride depended on various factors. The mean temperature influenced water consumption and hence the amount of fluoride to be added; other climatic conditions should perhaps be considered. Due regard must be paid to the fluorine content of the food.

Degrees of dental change—*Mr G. J. Parfitt* said that teeth showing blemishes or "mottling" were found in every community. Degrees of tooth blemish in high fluorine areas were: 1) Severe—extensive dark brown staining, hypoplasia and chipped enamel; 2) moderate—light brown staining; 3) mild—paper-white streaks, lines across the enamel surface and patches; or 4) questionable—white flecks at the tops of the teeth, particularly the premolars, and sporadic flecks and patches on the labial surface of the teeth. Venkateswarlu had suggested an index to include both the incidence and degree of mottling prevalent in a community by giving a score to each case, severe counting as 4, moderate as 2 and mild as 1, the resultant score being expressed for 100 persons. By this index, West Mersea (5–6 p.p.m.F.) scored 101, Harwich and Manningtree (2–3 p.p.m.F.) scored 60, Colchester (1–2 p.p.m.F.) scored 33, Slough (1 p.p.m.F.) scored 5. The incidence of questionable grades of mottling in London children (0·1 p.p.m.F.) was above 50 per cent. Some of these cases might be considered to show a mild degree, because paper-white, yellow and brown patches might cover a large surface of one or more teeth, some being indistinguishable from those found in high fluorine areas.

Factors influencing fluorosis—*Dr Dagmar C. Wilson* stated that endemic fluorosis might be caused not only from the chronic absorption of fluorine in food and water but also from the continued industrial use in certain areas of local compounds that naturally contain fluorine. In studying the world distribution of fluorosis local variation in geological structure assumed importance; in this country the many factors that influenced the various sources of a water supply should not be overlooked. The toxic effects of endemic fluorosis were intimately related to body structure and to nutrition. Fluorine was eliminated by the kidney and it was natural to look for lesions in the urinary system. A vast field for study had been opened up by the recent work of Peters on the toxic effects due to interference with enzyme systems in the kidney by fluorine compounds such as fluoroacetate. It was interesting to note that the fluorine and bladder-stone areas of the world overlap. Also congenital cataracts in people showing severe dental fluorosis deserved consideration.

Distribution of fluorides in teeth—*Dr G. Neil Jenkins* described how the concentration of fluoride on the surface of enamel from permanent teeth had been found to be much higher than within, but in deciduous teeth the distribution was more uniform. At least part of the surface fluoride was laid down before eruption. The fluoride concentration of inner enamel, and especially of dentine, rose with advancing age even in "low fluoride" areas, thus showing that some storage of fluoride occurred when the intake was as little as 2 milligrams a day (the probable intake in this country). Variations in the carbonate concentrations of bone and enamel had been reported with high fluoride ingestion but no differences from normal had been detected in enamel from areas with 1–2 p.p.m. of fluoride in the water. It had been suggested that fluoroses enamel might have antibacterial properties. The evidence so far published was inconclusive and based on enamel heavily fluorised by application of sodium fluoride *in vitro*. The results of solubility studies on the outer surfaces of intact teeth had not been entirely consistent, but, taken as a whole, they did not support the belief that the anti-caries action of fluoride was exerted through this mechanism.

SOUTH-WEST ORTHOPAEDIC CLUB

The South-West Orthopaedic Club met at the Princess Elizabeth Orthopaedic Hospital, Exeter, on November 20, 1954.

Clinical cases—*Mr R. Merryweather* showed two cases of traumatic paraplegia treated by early operation and plating and grafting, and two cases of complete paraplegia treated on Stoke Mandeville lines. He also gave a brief report on twelve cases of traumatic paraplegia dealt with during the previous twelve months.

Mr C. C. Jeffrey demonstrated three patients with pollicisation of the index finger, two with congenital absence of the thumb and the third, a one-armed man, with a traumatic amputation of his only remaining thumb. The technique followed had been that described by Cuthbert and he explained the difficulties of the procedure.

Mr G. Blundell Jones demonstrated two children who had suffered from bilateral paralytic dislocation of the hip and were treated by subtrochanteric osteotomy. The dislocation in one was the result of cerebral palsy and the other followed poliomyelitis; both children were now able to walk.

Mr J. Pyper showed three patients: 1) Slipped upper femoral epiphysis treated by pinning with Austin Moore pins. 2) Infantile coxa vara with a cervical angle of 45 degrees corrected by osteotomy and nailing with a Capener-Neufeld nail-plate. 3) A girl of twelve with genu valgum and four inches separation at the ankles treated by femoral osteotomy-osteoclasis.

Mr E. Percy demonstrated two cases of arthrodesis of the hip using the central dislocation method of Charnley and a postero-lateral approach. The acetabulum was reamed with a carpenter's wood tool, a 1½-inch Forstner auger bit, and the head was shaped with a home-made hole saw.

Mr Campbell White showed four recent results of McMurray displacement osteotomy, three for osteoarthritis and one for non-union of a subcapital fracture of the neck of the femur. He also showed one patient with osteoarthritis of the hip, without marked bone changes, treated by capsulectomy.

A visit was paid to the Orthopaedic Workshops of the Devonian Orthopaedic Association in the hospital grounds. The new workshops had been completed in January 1954 and were as well equipped as the best in the country.

Myelomatosis—*Dr G. Stewart Smith* introduced *Dr J. O. Edgecumbe*, who talked on the blood changes in myelomatosis. He stressed the value of sternal or iliac marrow biopsy. *Miss M. M. McCreedy* explained the apparatus used for investigations of plasma proteins by the electrophoretic method and its particular application to myelomatosis. By the fractionation method a particular pattern was found in myelomatosis.

Calcification about the hip—*Mr G. Blundell Jones* read a paper on acute episodes with calcification around the hip. Calcified deposits in the supraspinatus tendon at the shoulder might rupture and cause very acute pain and gross limitation of movement, but with rest and sedation the condition cleared up spontaneously with absorption of the calcium. Six cases were reported in which there had been calcification in the region of the hip, with sudden onset of very severe pain in the hip and gross limitation of movement with muscle spasm. Heavy sedation and rest in bed were required, but function was steadily regained over two to four weeks. Radiographs showed calcification at the onset and almost complete absorption three or four weeks later. A similar condition at the elbow was also shown.

Fracture-separation of the lateral condylar epiphysis of the humerus—*Mr C. C. Jeffrey* reviewed cases of fracture-separation of the epiphysis of the lateral condyle of the humerus and drew attention to the incidence of non-union in certain cases of minor displacement. He advised bone grafting in these to minimise late deformity with its complications. He demonstrated also how soft-tissue suture seldom gave the exact reduction desirable in fractures involving articular surfaces when it was used in open reduction of those cases with gross displacement. He recommended screw fixation, the screw being placed in that part of the diaphysial bone which is so consistently displaced with the epiphysis itself.

Treatment of osteochondritis—*Mr K. H. Pridie* discussed a new approach to the problem of treatment of osteochondritis. He demonstrated by slides that the nutrition of the articular cartilage was dependent upon the healthy state of the bone beneath. Where vascular lesions were present in the bone, the cartilage was shown to suffer. Radiographs and pictures were demonstrated of a fracture of the lateral condyle of the femur. At operation small islands were found to be growing on the raw cancellous bone. These islands had become detached from the rest of the condyle, which was severely comminuted. It was demonstrated also that osteochondritis dissecans was probably due to an infarct in the bone, causing a vascular calamity under the cartilage. The cartilage became detached and a loose body was produced. In three cases the avascular bone had been excised to a depth of one inch, and in one case almost the whole of the lateral femoral condyle was removed and replaced by cancellous graft taken from the upper end of the tibia. A

cartilage graft was placed over the cancellous bone; two cases were shown in which this operation had been performed and the patients had excellent function a year later.

The ankle in relation to tarsal arthrodesis—*Mr R. H. C. Robins* reviewed the late results of sixty operations. The length of the follow-up was about twenty years in most cases. Many patients showed increased lateral movement of the talus within the ankle mortise, with corresponding rounding of its margins radiographically, but this did not cause clinical instability unless there was also persistent varus or valgus deformity of the foot. In the period under review, significant osteoarthritis of the ankle was not seen. Cases of flail foot associated with paralysis of the quadriceps were much improved if the ankle joint was included in the fusion (pan-talar arthrodesis) to assist stability of the knee in extension.

Spinal fusion—*Mr Hugh Morgan* reported the long-term results of spinal fusion in the treatment of scoliosis in an analysis of 100 cases. The results were correlated with the age of onset of the curvatures, and it was shown that the best results were obtained in adolescent or late-onset scoliosis. The failure of spine fusion to influence the progression of infantile idiopathic scoliosis was demonstrated.

Injuries of the cervical spine—*Mr F. C. Durbin* reported fifty-three cases of fractures and dislocations of the cervical spine, occurring during the previous ten years. Forty-three involved C.3–C.7. There were twelve cases of complete paraplegia, eleven fatal. The remaining patient had no recovery and was still in hospital after three years. Among the cases was one of true cervical spondylolisthesis. Mr Durbin demonstrated the value of flexion films to determine stability, and of oblique films in making the diagnosis of locked facets. The maintenance of reduction was difficult and in some instances redisplacement occurred after six months' immobilisation. He felt that early grafting and wire fixation was the treatment of choice: it allowed early activity, recurrence of the deformity was prevented, and the period of immobilisation was reduced to three months.

Historical collections—*Mr Norman Capener* gave a short talk on historical books of orthopaedic interest from the Exeter Medical Library and the Library of Exeter Cathedral, which together was one of the more important collections of historical works in this country. Copies of works by Abernethy, Astley Cooper, Brodie, Cheselden, William Cowper, Eustachius, Galen, Gutherie, Havers, William and John Hunter, Kerking, Percivall Pott and Vesalius were among those displayed.

In the evening the annual dinner was held, and after this Mr Noel Wilson gave a very interesting talk on his recent tour in North America as a British and Commonwealth exchange fellow in orthopaedic surgery.

EAST ANGLIAN ORTHOPAEDIC CLUB

A meeting of the East Anglian Orthopaedic Club was held at the East Suffolk and Ipswich Hospital on November 27, 1954, with Mr Noel Smith in the chair. Clinical cases were shown.

Multiple myelomatosis—*Mr T. Denness* demonstrated a pathological fracture of a humerus at the site of a neoplasm. This had been the patient's presenting symptom, but sternal puncture showed that she was suffering from multiple myelomatosis. She died soon afterwards.

He also showed a second case of myelomatosis presenting with sudden pain in neck and arm. Radiographs showed collapse of the body of the fourth cervical vertebra. The diagnosis was established by sternal puncture.

Metastases from a hypernephroma—A man was shown with a swelling of the third metacarpal which looked clinically like a Brodie's abscess. Radiographs showed destruction of the metacarpal. This was resected and the section showed the presence of a neoplasm, probably from a hypernephroma. This was described by *Dr A. B. Lintott*, pathologist to the East Suffolk Hospital. The possibility of its having arisen from the prostate was considered, but the normal blood chemistry was against this. Investigation of the kidneys showed doubtful changes in the left kidney. Dr Lintott pointed out that secondaries from a hypernephroma were so often apparent before the primary was suspected that he would have liked the left kidney explored.

Fracture at lower end of femur and Charcot's arthropathy—*Mr E. Bell Jones* showed a case of a woman of forty-two complaining of pains in her feet and an unsteady walk. Radiographs showed a lesion of the lumbar spine thought to be tuberculous. Under treatment, healing had taken place in nine months. At about this time she developed a painless swelling round the knee and was found to have a fracture at the lower end of the femur. She was then discovered to have a positive Wassermann reaction and had in fact a Charcot's osteoarthropathy. In discussion *Mr M. C. Wilkinson* said he had never seen a tuberculous lesion of a lumbar spine with neurological signs from pressure. Those thought to be tuberculous always later proved to be something else.

Osteoid osteoma—*Mr Bell Jones* demonstrated the case of a patient with constant pain in the left groin for five years but in whom there were no physical signs until repeated radiographs presently showed a lesion in the neck of the femur. Several months in bed gave no relief but the insertion of a Smith-Petersen nail gave immediate relief. It was suggested that the lesion was an osteoid osteoma. In discussion some suggested that the lesion was a stress fracture, but this was not generally agreed.

Congenital absence of both patellae—*Mr Bell Jones* showed a boy with congenital absence of both patellae. The boy complained of some weakness in his left leg and said he could not keep up with other boys. Radiographs showed the absence of the patellae but there was a palpable thickening on the outer side of the knee and this was thought to be a patellar tendon. Mr Bell Jones proposed to explore this and transplant it to the front of the tibia. *Mr Noel Smith* reported that the condition was common in Holland but caused no loss of function.

Dislocation of the head of a radius in a small child—*Mr Bell Jones* showed a child with dislocation of the head of a radius, confirmed by radiography, which also showed the presence of a bony loose body. At exploration the head was found to be entirely free. Discussion centred on whether the dislocation was congenital or traumatic.

Aseptic necrosis of head of radius—*Mr T. Denness* showed a case of aseptic necrosis of the head of the radius. There was no pain at all and only a little loss of pronation and supination. He suggested removing the head in spite of the lack of symptoms in the hope of increasing the range of movements and preventing further damage to the joint.

Discoid or cystic lateral cartilage—*Mr Bell Jones* showed a small boy who for six months had had inability fully to extend his right knee. The trouble was of sudden onset. There was a little fullness on the outer side of the knee; the radiographs were normal. He proposed to explore the knee expecting to find a discoid or cystic lateral cartilage.

A further meeting was held at Addenbrooke's Hospital, Cambridge, on February 5, 1955, with Mr G. K. McKee in the chair.

Osteomyelitis of the head and neck of femur—*Mr A. G. Quinlan* showed a child in whom osteomyelitis in infancy had caused complete necrosis of the head and neck of the femur. Now ten years old, she walked well with a high boot and could run. The possible value of arthrodesis or a shelf operation was discussed, but it was generally felt that she should be left alone until her function began to deteriorate or until she got low back pain, when femoral osteotomy should be advised.

Sclerosis of the femoral head—*Mr Quinlan* showed a boy of seven in whom an infected laceration of the knee had been followed by pain and limitation of movements at the hip. He was found to be diabetic. The Mantoux test was negative and aspiration of the hip produced a clear straw-coloured fluid sterile on culture. He was put into plaster for two months. Gradually he was found to develop sclerosis of the femoral head. Another case was that of a boy of three who had had one week's febrile illness, with possible widening of the joint space. Aspiration of the hip produced clear fluid, and ten days later pus. On neither occasion was any organism grown. He was treated by limb traction, and later by immobilisation on an abduction frame. Radiographs showed sclerosis of the femoral head; the changes gradually became less marked and the most recent film suggested the beginning of regeneration.

Fracture-separation of the lower tibial epiphysis—*Mr R. W. Butler* showed three cases. He pointed out that they were usually easy to reduce and seldom followed by joint disturbance. Trouble arose from those that had also a vertical crack through the epiphysis. The first case demonstrated this: growth was irregular, and osteotomy above the epiphysis was required to correct the deformity. Discussion followed and several members emphasised their observation that the important lesion was not the displacement of the epiphysis but the fracture through it. *Mr R. Howard* reported that he had succeeded in preventing deformity by stapling the outer side of the epiphysis.

Avulsion of the lesser trochanter—*Mr J. F. Walker* showed a boy who had avulsed the lesser trochanter with muscular effort. Function had been restored without special treatment. Other members reported similar experiences.

Dislocation of knee—*Mr Quinlan* demonstrated a man who had sustained a dislocation of the knee from stepping into a hole in the ground. Attempted reduction failed. At open reduction it was found that the medial and cruciate ligaments had been torn and the capsule was folded into the joint. Reduction was accomplished easily after the capsule had been withdrawn.

Ankylosing spondylitis—*Mr Butler* showed a man of forty-four with ankylosing spondylitis treated by spinal osteotomy. He described the details of preparation and operation. The bone

wedge was removed at the level of L.2–3. Because he had stiff jaws a tracheotomy was carried out to facilitate the anaesthetic.

Focal osteitis fibrosa—*Mr G. S. Plaut* showed a patient with pain, stiffness and deformity of the lower end of the radius. She had been in the London Hospital in 1932 and had had a full investigation with a biopsy which was reported as "focal osteitis fibrosa." When she was recently admitted to Addenbrooke's Hospital a biopsy showed a probable sarcoma. Amputation was carried out. *Dr R. A. Parker*, pathologist to Addenbrooke's Hospital, described the section and pointed out that glands were found to be involved, which was unusual in a sarcoma. He emphasised the interest in a case of a malignant tumour being superimposed upon a benign condition that had been present for twenty years.

Adamantinoma—*Mr Plaut* showed a man of twenty-four who had had pain in the right knee after knocking it. Radiographs showed a diffuse shadow in the head of the tibia. The pain subsided, but recurred six weeks later with some effusion. Tomographs revealed a tumour, which at operation was found to be a greyish mass and obviously malignant. Amputation was carried out. *Dr Parker* explained that the tumour was an adamantinoma. These had been thought to be benign, but work at the Mayo Clinic had shown them to be malignant and metastasis had been found.

AUSTRALIA

AUSTRALIAN ORTHOPAEDIC ASSOCIATION

The Annual Meeting of the Australian Orthopaedic Association was held in Melbourne from August 13–17, 1954. The meeting was attended by approximately eighty members and associate members. At the business session the following officers were appointed for 1954–55: president—Mr T. King; president-elect—Mr A. R. Hamilton; vice-presidents—Mr A. Dawkins, Mr J. Lahz and Mr N. P. Wilson; honorary secretary—Mr McClements Callow; honorary treasurer—Mr Hugh Smith; editorial secretary—Mr Warwick Stening; executive committee—Mr L. Macdonald, Mr D. Sturrock, Mr A. S. Watts and Mr D. P. Rowe. The following were nominated as editorial committee of the *Journal of Bone and Joint Surgery:* the president, Mr King; the honorary secretary, Mr Callow; and the editorial secretary, Mr Stening.

Acrylic arthroplasty of the hip—*Mr Thomas King* (Melbourne) showed three cases illustrating acrylic arthroplasty of the hip. In these three cases Mr King had employed the new oblique prosthesis of Judet, and he pointed out its mechanical advantages. Although the technique was more difficult than that of inserting the ordinary Judet prosthesis, this was outweighed by the mechanical advantages of this new prosthesis. He also emphasised that, in accordance with Judet's teaching, only a very limited division of capsule should be made, to preserve the blood supply to the end of the femur. He used an anterior incision routinely in this operation. In discussion, *Mr Hugh Barry* (Sydney), *Mr E. West* (Adelaide) and *Mr A. Dawkins* (Perth) all stated that they preferred the posterior approach to the hip joint. *Mr J. B. Colquhoun* (Melbourne) thought that the anterior limited approach used by Mr King was difficult and seriously prolonged the operating time.

Compression techniques—*Mr W. Gayton* (Melbourne) showed three cases illustrating the use of contact compression. His first case was that of a man with fractures of the right tibia and fibula. Compression was obtained by the use of a slotted plate and transfixion pins through the tibia above and below the fracture, compressed with a clamp. The man resumed work six months after this operation. The second case illustrated compression employed in arthrodesis of a knee joint. The third case showed the same technique employed for bone union in a fracture of the mid-shaft of the humerus. Union was claimed three months after operation. In discussion *Mr E. West, Mr McC. Callow* (Sydney), *Mr P. Williams* (Melbourne) and *Mr T. King* spoke in favour of the compression technique in knee arthrodesis. *Mr D. W. Parker* (Hobart) preferred erasion of the joint and onlay bone grafting in delayed union of fractures. Apart from Mr King no speaker had had experience of the use of compression methods in dealing with fractures of long bones. The dangers of sepsis and pin-track infections were pointed out by *Mr A. R. Hamilton* (Sydney).

Arthroplasty of the elbow—*Mr B. T. Keon-Cohen* (Melbourne) showed three cases of arthroplasty of the elbow for severely comminuted fractures. In discussion, speakers stated that they were impressed with the excellent functional results in the cases shown. *Mr R. D. McKellar Hall* (Perth) said that if one accepted the inevitable flail elbow it was one of the most satisfactory destructive operations. *Mr A. L. Webb* (Sydney) said that a will to use the elbow was all-important in achieving a good result, and arthroplasty was usually an unsatisfactory procedure in Workers' Compensation cases. *Mr D. P. Rowe* (Sydney) thought that the immediate treatment of these badly shattered elbows should be conservative. He thought the function of most stiff elbows was

quite good. *Mr J. E. Critchley* (Melbourne) had used the technique mainly in dealing with elbows stiff from rheumatoid arthritis and stated that his results had been good.

Spondylolysis—*Mr Eric Price* (Melbourne) demonstrated three cases of spondylolysis treated surgically after failure of conservative measures for relief of low back pain, associated in two of the three cases with sciatic pain. Each case showed an interarticular defect of the fifth lumbar vertebra, in two of the cases with a slight forward slip. At operation in each case a loose lamina and spinous process were found. The loose piece was removed. Mr Price had done the operation in ten cases, with good results in all. In discussion *Mr A. F. Dwyer* (Sydney) and *Mr Douglas Sturrock* (Sydney) expressed doubt as to whether the patients would be fit to resume heavy work. *Mr W. L. Kermond* (Melbourne) favoured removing the loose posterior element, and then removing the disc, erasing cartilage from the vertebral bodies, and filling the space with cancellous bone. After this operation he allowed his patients out of bed in ten days. Mr Callow expressed doubt about the long-term results. Mr Price, in reply, said that he could not speak on long-term results. The first of his cases was done only ten months ago. He stressed that it was a very simple operation.

Scoliosis—*Mr W. E. Swaney* (Melbourne) showed three cases illustrating the surgical treatment of scoliosis. In each, scoliosis had followed poliomyelitis contracted in early childhood. Two-stage spinal fusions were performed in adolescence.

Dislocation of the cervical spine—*Mr P. Williams* (Melbourne) showed three cases of dislocation of the cervical spine. In each case internal fixation by wires or grafts was used to prevent recurrence of subluxation. In discussion, Mr Keon Cohen expressed his disappointment with cases of dislocated neck treated conservatively. In most some redisplacement recurred. This view was supported by *Mr Parker*. *Mr McKellar Hall* described a case in which conservative measures failed but an excellent result was obtained from bone grafting.

President's address—In Mr Lennox Teece's absence abroad, the address was read by Mr A. S. Watts (Sydney). The president graphically described his impressions of orthopaedic surgeons and clinics in Italy, and gave some general impressions of his tour of that country.

The short tendo calcaneus—*Mr A. R. Hamilton* (Sydney) stated that minor degrees of limitation of dorsiflexion were common in people with "metatarsal" symptoms and signs, such as metatarsalgia, callosities and bursae beneath the heads of the metatarsals. When combined with a highly arched foot these symptoms were exaggerated and developed at a younger age. In treatment he recommended passive stretching, special exercises designed to stretch the tight calcaneal tendon, and wedged plasters according to the age of the patient and the severity of the symptoms and signs. For the remaining and relapsed cases he recommended open elongation of the tendon. He advised against this in infants, for relapse was frequent. In cases with athetoid spasticity there was a risk of calcaneus deformity after tendon lengthening.

Spinal fusion—*Mr C. M. Maxwell* (Sydney) gave an analysis of ninety-six cases of spinal fusion done between 1945 and 1953 at the Repatriation Military Hospital, Sydney. The operation was a modified Hibbs fusion in sixty-nine (12 per cent failed), Hibbs operation in thirteen (four failed), and H-graft in fourteen (no failure). Operation was performed for intervertebral disc lesion in thirty-eight, spondylolisthesis in thirty, tuberculosis in twenty-one, old fractures in four, unstable spine in two, and spondylitis in one.

Osteochondritis dissecans—*Mr D. J. Glissan* (Sydney) whose paper was read by Mr Dwyer, believed that the primary cause of osteochondritis dissecans in the knee was the pull of the anterior cruciate ligament. He pointed out that the attachment of this ligament was by strong fibrous bands, and that an extension of this insertion went to the area of the medial condyle where the sequested fragment was found. He suggested that the pull of the ligament had the effect of devitalising and perhaps raising a fragment of cartilage and underlying bone. He quoted several cases of this condition occurring in subjects who had been in the habit of sitting on their feet or squatting for long periods, positions which caused a considerable stretching force on the anterior cruciate ligament. In some cases the avoidance of such knee positions had resulted in spontaneous cure of the osteochondritis. He regarded it as a valuable sign of the condition that pain occurred especially on forcible knee flexion or squatting.

In discussion it was pointed out by several speakers that this hypothesis did not seem to offer an explanation for osteochondritis dissecans occurring in sites other than in the medial femoral condyle of the femur.

Synovial cysts in bone—*Dr J. D. Hicks* (Melbourne) said that the nature of many translucent areas in bone could often be finally determined on the operating table and pleaded for adequate biopsies. Cysts of bone containing synovial fluid were common in osteoarthritis, but the cysts he intended to describe were not commonly near a joint and apparently had no communication with a joint. He described several cases, illustrated by radiographs and microscopic sections. In three cases and a possible fourth he considered the pathological findings indicative of a true cyst of

bone limited by synovial membrane and containing some synovial fluid. The sites of these cysts were the medial malleolus, the upper end of the tibia, the olecranon, and probably the calcaneum. He suggested that these cysts might possibly be of the same nature as the unicameral bone cyst. He thought that injury probably played a part in the etiology, and that the cysts represented a local metaplasia. In some cases this metaplasia might be reversible.

Posterior dislocation of the shoulder—*Mr Stuart Scougall* (Sydney) described his experience with three cases, emphasising that it was a rare condition. He described experimental work in which artificial separation of the labrum glenoidale had been produced in monkeys. It appeared that reattachment of the labrum could occur. *Mr J. R. S. Lahz* (Brisbane) said that members whom he had questioned at the meeting had given details of twenty-one cases of posterior dislocation. A large proportion were chronic cases, and they had been treated variously with posterior bone block, reefing of the posterior capsule, and Nicola's operation. He explained the importance of a supero-inferior radiograph; without it a posterior dislocation could easily be missed.

Arthroplasty of the hip—*Mr W. Stening* (Sydney) discussed operative technique and difficulties in the Judet type of arthroplasty. He preferred the postero-lateral approach described by Gibson in most cases, and used the limited anterior approach only for recent femoral neck fractures, especially in old people. He thought it unwise to remove the greater trochanter, and described several cases of non-union and slip of the prosthesis after removal of the trochanter. Mr Stening discussed the direction of the stem of the prosthesis. He thought that the base of the stem should engage in the cortex of the femoral shaft to improve stability. The size and type of prosthesis was also discussed. He had found the Lusterlite product very reliable.

In discussion *Mr L. J. Woodland* (Sydney) said that in cases of recent fracture a lateral incision was most satisfactory. *Mr D. P. Rowe* (Sydney) used only the posterior approach. He described four cases with fracture of the prosthesis, two in the stem and two in the gutter of the head. He preferred not to remove the capsule. *Mr A. I. Rhydderch* (Sydney) described thirty-two cases. There were three permanent dislocations. In two of these there was marked anteversion of the femoral neck and he thought that a rotation osteotomy should have been done first. *Mr Parker* recommended draining the wound as sepsis was a real menace. *Mr F. V. Stonham* (Melbourne) preferred the Austin Moore prosthesis when the femoral neck was short. He still preferred the Smith-Petersen type of operation and he doubted the lasting qualities of the acrylic material.

Fractures of the neck of the femur—*Mr F. McL. Callow* (Sydney) outlined principles in operative technique and management. He emphasised that in many of the poor results from the nail's cutting out of the head in the early post-operative period the nail had been badly inserted. He said that immediate osteotomy was indicated when there was radiological evidence that union was unlikely with nailing. In subcapital fracture in elderly people he thought that it was best to replace the head with an acrylic prosthesis rather than hope for union with a Smith-Petersen nail.

In discussion *Mr J. J. Woodward* (Melbourne) said that there were two classes of failure: early, in the first six weeks, from poor fixation at operation; and later, after eight or nine months, from necrotic changes in the head and neck. He always got the patient out of bed on the day after operation. *Mr Webb* mentioned cases in which, despite adequate insertion of the nail, the neck later absorbed. He thought there was no way of overcoming this complication. *Mr Keon Cohen* said that he now employed the Judet prosthesis in most patients over seventy or eighty years old. He said that in this group non-union was likely and with a prosthesis it would be possible to get the patient out of bed early. *Mr Hamilton* said that he always used a caliper in after-care, and most of his patients gained satisfactory union.

DENMARK

SCANDINAVIAN ORTHOPAEDIC ASSOCIATION

A meeting of the Scandinavian Orthopaedic Association was held in Copenhagen from June 10 to 12, 1954, under the presidency of Dr Sv. Klaer of Copenhagen.

The main subject was operative treatment of osteoarthritis of the hip. *Drs Carl Semb* (Oslo), *Gunnar Wiberg* (Lund), and *Eivind Thomasen* (Aarhus) introduced the subject. The second topic was the treatment of pseudarthrosis after fractures of bones, introduced by *Dr A. Bertelsen* (Copenhagen). A report of the many papers read at the meeting is given in Acta Orthopaedica Scandinavica.

In connection with the meeting a demonstration at the Orthopaedic Hospital, Copenhagen, was given of the various aspects of this hospital's work. A visit was also arranged to the hospital's Country Branch in Hornbaek for physical rehabilitation of poliomyelitis cases.

DANISH ORTHOPAEDIC ASSOCIATION

A meeting was held in Copenhagen on November 27, 1954.

Low back pain treated by distraction—*Dr Jens Bang* (Copenhagen), in charge of the physiotherapeutic department of the Orthopaedic Hospital, Copenhagen, reported 100 cases of low back pain treated on a table with a distraction force of 25 to 75 kilograms for half an hour every other day. Each patient was given about ten treatments. Half the patients were thought to have a herniated lumbar disc. The immediate result was relief of pain in about half the cases, but the symptoms were not improved in the other half. Treatment was stopped in thirteen cases because of temporary increase of pain. The results were slightly better in the group of herniated discs. No long-term results were given. If response to treatment was not obtained after six or eight distractions further treatment was unlikely to be of any help.

" Kissing " spines—*Dr J. Balslev Jørgensen* (Copenhagen) reported thirty cases of " kissing " spines operated upon in the Orthopaedic Hospital, Copenhagen, with partial resection of the spinous processes. In eight cases pain was totally abolished, nine patients were better, and thirteen unaltered. In the group of cases in which " kissing " of the spines was the only abnormality detectable on the radiograph the results were best and it was concluded that in such cases operation was indicated.

Syndactylism—*Dr Lis Zachariae* (Copenhagen) reported about seventy children with syndactylism operated upon at the Orthopaedic Hospital, Copenhagen. In most cases the operation was a flap-plasty for reconstruction of the webb, with free skin grafting on the inner sides of the fingers, the suture lines being more or less straight. In quite a considerable number of cases some contracture had developed, requiring a Z-plasty in some of the cases. A new method of operation was suggested and was tried out in a few cases: division of the fingers after preparation of multiple volar and dorsal flaps to diminish free skin grafting and avoid suture lines crossing joint creases.

Habitual dislocation of the shoulder—*Dr E. H. Guldhammer* (Copenhagen) and *Dr S. Michelsen* (Copenhagen) reported fifty-two cases of habitual shoulder dislocation operated on in the Orthopaedic Hospital, Copenhagen. Thirty-two were treated according to Bankart's method and twenty by Hybinette's method. In both groups the operation failed in four cases.

Acromio-clavicular dislocation—*Dr E. Bandler* (Copenhagen) gave a survey of the literature concerning methods of treatment of acromio-clavicular dislocation and reported fifteen cases operated upon by various methods with various results.

Free tendon grafting in repair of flexor tendon injuries in the fingers—*Dr K. Bang Rasmussen* (Copenhagen) reported thirty-six cases operated upon by himself in the Orthopaedic Hospital, Copenhagen. In fourteen cases previous attempt at repair had been made. The classification of results was according to Boyes: thirteen were good, twelve satisfactory and eleven bad. The proportion of good results was best among those operated upon most recently.

Acrylic arthroplasty of the hip—*Dr R. Movin* (Copenhagen) described the technique of acrylic arthroplasty of the hip now in use at Department I of the Orthopaedic Hospital, Copenhagen. Gibson's incision was preferred. The stem of the prosthesis was steeply graded in order to rest on the calcar femorale and to perforate the lateral cortex. The supporting surface of the acrylic head was horizontal. In order to give the medial gluteal muscle an increased lever, this muscle was fixed to a block of bone anchored to the outside of the trochanter.

INTERNATIONAL SOCIETIES

THIRD EUROPEAN RHEUMATOLOGY CONGRESS

The Third European Rheumatology Congress will be held at Scheveningen in Holland from June 13–17, 1955. The main subjects for discussion are as follows: June 13—Rheumatism and social medicine. June 14—Connective tissue lesions; osteoarthritis of the spine and disc degeneration. June 16—Rheumatic fever. Application for membership of the Congress should be submitted before May 1, 1955, to the Secretariate: Burg. de Monchyplein 9, The Hague. Copies of the programme and forms of enrolment may be obtained from the secretary of the congress, who will be pleased to supply any further information.

SECOND INTERNATIONAL CONGRESS OF PHYSICAL MEDICINE

The Second International Congress of Physical Medicine will be held in Copenhagen from August 20–24, 1956. The following are the main subjects on the programme. 1) The physiology of heat regulation and temperature and their relations to peripheral and central circulation as basic problems within physical medicine. 2) Applied physiology of the striated muscle as basic

discipline within physical medicine. 3) Physiology, diagnostic significance and treatment of pain in relation to physical medicine. 4) Rehabilitation on a scientific basis, especially with a view to the pathophysiology of muscle and evaluation assessment. The latest date for receipt of papers for presentation will be January 1, 1956. Enquiries regarding the congress should be addressed to the Honorary Secretary, B. Strandberg, M.D., Københavns amts sygehus i Gentofte, Dept. of Rheumatology and Physical Medicine, Hellerup, Denmark.

COMMENT

BONE ANOMALIES OF THE TARSUS IN RELATION TO PERONEAL SPASTIC FLAT FOOT

PROFESSOR ROBERT I. HARRIS

To the Editor,
Journal of Bone and Joint Surgery.

Sir,—The paper by the late E. A. Jack on Bone Anomalies of the Tarsus in Relation to Peroneal Spastic Flat Foot appearing in the November 1954 issue of the Journal is of great interest and importance. It is the first authoritative report on the subject since our original paper in 1948.

Some statements in Mr Jack's paper deserve comment. He rightly stresses the existence of peroneal spasm in certain cases, especially after trauma. In our original paper we reached the conclusion that peroneal spasm was not a factor in this condition; indeed we thought it did not exist and believed that what seemed to be peroneal spasm was in fact adaptive shortening of the peroneal muscles secondary to the valgus deformity. This must have resulted from the fact that the cases we reported then were examples of complete or nearly complete talo-calcaneal bridge or calcaneo-navicular bar. At any rate since 1948 we have come to recognise cases of peroneal spastic flat foot in which peroneal spasm does exist and it can be accentuated by stress and relieved by rest.

For the most part these are cases of incomplete talo-calcaneal bridge. The special oblique posterior superior radiographic projection does not reveal the characteristic shadow of the talo-calcaneal bridge but secondary radiographic changes are to be seen in the radiograph taken with a horizontal beam. These secondary changes are : 1) lipping of the superior margin of the head of the talus; this finding varies in severity and sometimes is absent; 2) obliteration of the joint between the sustentaculum tali and the neck of the talus; this is almost constantly present; and 3) thinning or absence of the joint space between the body of the talus and the body of the calcaneum.

By operation it can be demonstrated that these patients have an incomplete talo-calcaneal bridge. They are vulnerable to injury because with partial stiffness of the subtalar joint undue stresses cannot be absorbed by movement at the tarsal joints. Strain of the ligaments occurs and this is accompanied by peroneal spasm. The stress initiating the peroneal spasm may be a single trauma or it may be the repeated stresses of a particular way of life. I would say that the history and radiographs of the case illustrated by Figure 14 in Mr Jack's paper are characteristic of rigid valgus foot due to incomplete talo-calcaneal bridge. The lateral radiograph is characteristic since it shows a spur at the superior margin of the head of the talus, lack of visualisation of the joint between the sustentaculum tali and the neck of the talus, and lack of the joint space between the body of the talus and the body of the calcaneum. The lip on the superior margin of the head of the talus is similar to that shown in Figure 10 of Mr Jack's paper and in my experience is characteristic of a lesion which completely or partially anchors movement at the subtalar joint.

It should be emphasised that the peroneal spasm which develops in these cases is not the cause of the patient's deformity but is secondary to stresses upon a stiff tarsus.

Observations upon a group of cases with incomplete talo-calcaneal bridge were the subject of a paper read before the American Orthopaedic Association in June 1953 and published in the January 1955 number of the American edition of the Journal. I trust that this paper will serve to enlarge our knowledge of the problem of rigid valgus foot.

One further comment upon Mr Jack's paper is necessary for the sake of accuracy. It was not our intention to leave the impression that " these anomalies frequently cause trouble in early childhood," and re-reading of our paper reveals no statement to that effect. Most of the patients reported in our original paper were over fourteen years of age. There was one youth, however, who had been treated from infancy for severe resistant congenital calcaneo-valgus (Figs. 18 and 19). Review of his problem at age twelve revealed the cause of his deformity to be a complete talo-calcaneal bridge. This led us to the speculation that perhaps congenital pes calcaneo-valgus is a rigid valgus foot manifesting itself in infancy by severe deformity. We have had no opportunity since then to confirm this suggestion.

There was another early case recorded in our paper of 1948 (Figs. 9 to 11). She was thirteen years of age at the time her problem was radiographically investigated. But she had been under treatment for her rigid valgus foot for five years prior to that time, and had been observed to have unilateral flat foot from infancy.

Since then we have encountered a rigid valgus foot in a five-year-old child. The deformity is slight. Pain developing after instruction in ballet dancing brought her for advice. Her radiographs show no secondary abnormalities in the lateral projection but an abnormal sustentaculum tali is seen in the posterior superior oblique projection.

Since rigid valgus foot is now known to be due in many cases to congenital abnormalities of the tarsus it would be reasonable to expect that some evidence of the existence of the condition might be present in childhood. The disability must be less in childhood than it becomes in adolescence since many patients are firm in their statement that they had no foot disability until a certain moment. Further knowledge of the existence and significance of the condition in childhood probably will be obtained only by mass survey of foot problems in children.

Yours truly,

R. I. HARRIS.

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Book Reviews

TEXTBOOK OF OPERATIVE SURGERY. By Eric L. Farquharson, M.D., F.R.C.S. (Ed.), F.R.C.S. (Eng.), Surgeon, Royal Infirmary of Edinburgh, Member of Clinical Teaching Staff, University of Edinburgh. 10 × 6½ in. Pp. viii + 853, with 623 figures, some in colour. Index. 1954. Edinburgh and London: E. & S. Livingstone Ltd. Price 75s.

This is a good book in that it achieves its aim of presenting the whole subject of operative surgery in balanced perspective from the *viewpoint of the general surgeon in training*, and it will certainly help him to satisfy the examiners for the Fellowship of any of the Royal Colleges of Surgeons. The examiners are nearly all general surgeons, and since general surgery has now become a rather broad speciality, it is necessary for a candidate to learn the scope of his examiner's interests. The author states that operations that are less often performed, and those that lie more strictly within the specialised fields, are described more briefly and in small print. It is, therefore, possible to tell which operations a general surgeon regards as specialised: for example, the operative treatment of hare-lip is in small type, and that of congenital dislocation of the hip is in large; the repair of an injured ureter is in small type, whilst the repair of an injured sciatic nerve is in large: thoracoplasty is in small type, and operations for the relief of recurrent dislocation of the shoulder are in large; tumours of the brain are dealt with in small type, and tumours of bone in large; and the repair of a fistula of the bladder is in small type, whilst the repair of an old injury to a peripheral nerve is in large type. It seems that orthopaedic surgery is not regarded as a speciality.

These comments are a criticism of the present methods of training and examination which make this book necessary. They are not criticisms of the book itself which is worthy of much praise. The text is clearly written in simple language that reveals the orderly mind of the skilled teacher. It is profusely illustrated and the figures, many in colour, are so wisely selected and beautifully drawn that the veriest tyro could not fail to follow the descriptions—the amount of hard work which this has involved has to be experienced to be appreciated. The section relating to orthopaedic surgery is for the most part orthodox, but there is an occasional startling statement such as that, in congenital torticollis, a "sternomastoid tumour" should be excised without delay.—Philip Wiles.

AMPUTATIONS. By Leon Gillis, *M.B.E.*, M.B. (Witwatersrand), M.Ch.Orth. (Liverpool), F.R.C.S. (England and Edinburgh), Consultant Orthopaedic Surgeon to Queen Mary's (Roehampton) Hospital, London. Foreword by Sir Harry Platt, President of the Royal College of Surgeons. 10 × 8 in. Pp. xi + 423, with 342 figures. Index. 1954. London: William Heinemann Medical Books Ltd. Price £4, 4s.

It is unusual to find a book that covers so completely the conditions, both traumatic and non-traumatic, that justify amputation. In this book all these conditions are described, the non-traumatic ones at considerable length. The indications for amputation under different circumstances are given and are made additionally clear by the inclusion of a large number of photographs taken before operation. The best level and proper time to do these different amputations is laid down. The technique of doing the amputations at different levels is described, but the description of some of these is not very full and is often not accompanied by diagrams to illustrate the details of the operation. The whole book is extensively illustrated and contains a very comprehensive bibliography that includes almost everything that has been written in relation to amputations.

The section on congenital deformities and amputations in childhood is good, and the section on the use of extension limbs for very short legs is a helpful addition to a subject of which little is generally known. Besides his knowledge of the conditions that necessitate amputation the author shows a considerable familiarity with the late behaviour of stumps when they are fitted with artificial limbs, and describes at length the complications that may arise and their causes and treatment. Causalgia and phantom limbs are discussed, but apparently not much that is new has been developed to relieve these distressing conditions. It is rather pleasing to note that Syme's amputation is considered favourably if it is done at a low level where the cut ends of the bone are broad and the weight-bearing soft tissues are obtained from the sole of the foot.

The book contains a good deal that applies more to general surgery than to amputations. It is rather bulky for a text-book for students, but it is a very interesting and up-to-date book for anyone particularly interested in amputations.—A. B. LeMesurier.

LEGG-CALVÉ-PERTHES SYNDROME and Related Osteochondroses of Youth. By Charles Weer Goff, M.D., Assistant Clinical Professor of Orthopaedic Surgery, Yale University School of Medicine; Attending Orthopaedic Surgeon, Newington Home and Hospital for Crippled Children, St Francis Hospital, Hartford. In association with Ned M. Shutkin, M.D., and Myerma R. Hersey, M.S. 10¼ × 7½ in. Pp. xxiii + 332, with 124 figures. Index. 1954. Springfield, Illinois: Charles C. Thomas, Publisher. Price 77s. 6d.

This monograph covers the whole field of osteochondritis or, in the author's phraseology, "the osteochondroses." The illustrations are plentiful, clear and interesting. The collection of historical facts is most impressive and very useful for reference. A pleasant feature is the inclusion of portraits of men whose names are historically associated with various manifestations of osteochondritis and with many other aspects of orthopaedics, and this is unique. The whole book represents an enormous amount of work and careful industry. It is consequently surprising that no new concept or leading idea is recognisable. The whole picture is presented in meticulous and minute detail, but it seems to lack a theme or a message—as if on a signpost the road already travelled were exactly described but the arm pointing onward were blank.

The reader will find abundant and interesting material, but he will have to overcome a certain amount of irritation. The eternal repetition of the initials LCPS as a noun or an adjective becomes irritating to the point when it begins to hurt. The letters represent a contraction of the title—Legg-Calvé-Perthes Syndrome. The author speaks of "our series of LCPS"; "these LCPS children"; "such disorders are not LCPS *per se*" and so on *ad* more than *nauseam*. The reader will also have to disentangle some associations of words which tend to obscure the meaning; for instance "internal environmental genetic influences"; "fourth fundamental body build"; "one noxious element of a physiologic mechanical imperfection." And a certain amount of translation will be required in such instances as "prior typologies"; "superanthropomorphic measurements"; "photogrammetry"; "preponderant mesomorphic somatotype." For an author who has escaped "roentgenographological" to use these ponderous words is disappointing.

The description of treatments is extensive and deserves respect, although in many cases the choice or judgment of the best treatment may not gain approval. One is left with the feeling that a précis of this book would be invaluable.—Bryan McFarland.

TEXTBOOK OF THE RHEUMATIC DISEASES. Edited by W. S. C. Copeman, *O.B.E.*, M.D., F.R.C.P., Senior Physician, Arthur Stanley Institute for Rheumatic Diseases, Middlesex Hospital, Physician in charge of Department of Rheumatic Diseases, West London Hospital, Chairman, Empire Rheumatism Council, and late President, European League against Rheumatism; with twenty-five other contributors. Second edition. 9½ × 7½ in. Pp. viii + 754, with 349 figures, 11 in colour. Index. 1955. Edinburgh and London: E. & S. Livingstone Ltd. Price 52s. 6d.

In 1948 when we had the pleasure of reviewing this work we regarded it as an outstanding achievement. This is confirmed in the production of this splendid new edition, which contains nearly 150 more pages and over 100 new illustrations. It is superbly produced, and is a mine of information. A new section by Dr Oswald Savage upon the Adrenal Hormones is not only authoritative but is in a readable form that makes this complicated subject easily understood. The chapter on Rheumatic Fever has been rewritten by Lord Horder with the help of a new contributor, Dr E. G. L. Bywaters, and the section upon Rheumatoid Arthritis has been similarly dealt with by Sir Stanley Davidson assisted by Dr J. J. R. Duthie. In Rheumatic Fever we are glad to see the emphasis laid upon treatment by rest in the acute phase, and in this the similarity is drawn with poliomyelitis and with the need to distinguish early the end of this phase and the importance of commencing activity. In such a discussion we see one of the best examples of true medical orthopaedics; not least in the recognition of the social factors of education, etc. In Rheumatoid Arthritis the principles of treatment by rest and movement are also well stated, particularly in relation to the constitutional ill-effects of complete immobility. The importance of splints, mostly of plaster, in the acute stage is noted. Nevertheless, it is difficult to understand why physicians should be so enamoured of "skin-tight" plasters. Nor why, if there are good nursing and remedial gymnastics, they should frown upon the use of a knee pillow (which usefully supports the hip as well as the knee). Treatment by such drugs as gold, phenylbutazone, cortisone and ACTH is given suitable perspective, but surprisingly little is said about the use of salicylates. In spite of these quibbles, this is a first class contribution. Of the rest of the work we need say little more. Sir Henry Cohen contrives to write literature as well as science and, in this age of dry materialism, he warms one's heart. He will forgive us for mentioning that it was P. Jenner Verrall,

not *Jenner*, who gave the title of arthrokatadysis to protrusio acetabuli. In the section upon Osteoarthritis the illustration of the structure of articular cartilage, said to be " after Collins," is *from Collins* modified *after Benninghoff*. Actually, osteoarthritis is more convincingly dealt with in the later sections upon Pathology, Neurology and Orthopaedics. Psychiatry has not been well served in the rather superficial snippet provided. It seems specially hard on " strict Baptists, Salvationists, and Plymouth Brethren, etc." who are implicated in some dubious statistical reasoning which is based upon unbending attitudes of faith and posture. " Arthritic-like pains are, in our experience, relatively common (and often quite intractable) in " them. Relative to what?

The orthopaedic sections maintain their high standard. In the treatment of the osteoarthritic hip we are glad to notice the cautionary note upon the unreliability of arthroplasty. Nevertheless, we still find it difficult to accept the use of the word " ideal " as applied to arthrodesis, good as it may be.

In spite of such few criticisms Dr Copeman is to be congratulated upon producing a notable integration of diverse interests dealing with many diseases loosely called rheumatic. He has shown again that the good doctor must have knowledge of special fields and that every specialist must be a physician. His book is essential to the orthopaedic surgeon's library.—Norman Capener.

THE DIGITAL CIRCULATION. By Milton Mendlowitz, M.D., F.A.C.P., Associate Attending Physician, Mount Sinai Hospital, Research Fellow, Columbia University Division of Goldwater Memorial Hospital, New York City. 10¼ × 7 in. Pp. xii + 182, with 60 figures, 4 in colour, and 31 tables. Index. 1954. New York: Grune & Stratton. Price $6.75.

Dr Milton Mendlowitz was a pupil of Sir Thomas Lewis and gives praise to the British school of clinical research initiated by that great man. He also worked under Gross of Boston through whom his interests in shock were aroused.

In his preface Dr Mendlowitz states that although " acral circulation is subject to extreme fluctuation with temperature changes, pain or emotion, it may be stabilised by inhibiting sympathetic nerve discharge (by means of reflex heating) and may then accurately reflect non-neurogenic or intrinsic changes in the entire systemic circulation." Structural and functional changes in the circulation are often most manifest in the acral part of the circulation. Many methods for recognising such phenomena are available, such as skin temperature measurement, plethysmographic, photoelectric or calorimetric studies. He then briefly describes the history of measuring blood flow in the digits.

The first three chapters deal respectively with the anatomy, physiology and pharmacology of the peripheral vascular tree, the latter including useful tables of blocking drugs and of stimulating drugs, giving their sites and duration of action, as well as dosages and side effects. The fourth chapter gives a short account of the pathology of peripheral vascular disease and includes some good illustrations.

Then follows a chapter on methods, with brief descriptions of capillaroscopy, digital blood pressure, blood flow and pulse waves, plethysmography, oscillometry and colorimetry; Mendlowitz has concentrated especially on this latter method. The results of an enormous amount of observations are included, and the many diagrams, tables, and not a little mathematics, help to explain the results. The section on " digital vascular resistance and intravascular blood viscosity " makes difficult reading, at any rate to the clinician, even with some experience of research. For instance, " when blood is used as the perfusing fluid, the relationship between P_a and Q_a has been interpreted by different workers to be rectilinear with a shifting intercept on the pressure axis, hyperbolic and hence approaching an asymptote, or logarithmic." Or again, " Thus, in a typical calculation, if the arithmetic mean digital arterial pressure minus venous pressure is 52 mm. Hg. and the flow 0·0047 cc./sec./sq. cm. of skin, 5·2 cm. multiplied by 13·6 (specific gravity of mercury) and by 980 cm./second^2 (acceleration due to gravity) equals 69·306 dynes/sq. cm." Finally, a word is said on oxygen exchange.

Following this come brief descriptions of thromboangitis obliterans, scleroderma, thrombophlebitis and arteriosclerosis, with rather fuller ones of trench foot, frost-bite, and Raynaud's disease.

A special chapter on clubbing describes Dr Mendlowitz's own researches into this problem, both the congenital and acquired types, the latter including the bilateral and unilateral varieties. Some of the causes of unilateral, unidigital clubbing are aneurysms of the subclavian, innominate or brachial arteries, or injury to the affected digit. The author does not believe in the anoxaemic theory but in hyperaemia as a cause. " If there is an increase in pulmonary circulation for any reason, this must be followed by an increase in systemic circulation, and if the increase in the latter

is out of balance with the demand of the systemic demand for blood, the stage is set for the appearance of clubbing."

Dr Mendlowitz is a supporter of thoraco-lumbar sympathectomy for hypertension, and writes a most lucid chapter on the background of this common disease, pointing out the three responsible factors, namely, the neurogenic, humoral, and intrinsic, the latter being produced by intimal thickening, thrombosis, external constriction, and arteriolar muscular hypertrophy. He has studied by colorimetry the digital circulation in a long series of hypertensives. He remarks on the phenomenon of the annoying vaso-constriction in the hands that sometimes follows this operation, yet " despite these considerations, there is good evidence that sympathectomy is of some value in selected cases of essential hypertension," a conclusion which the results obtained in Birmingham confirm.

This is an excellent book, one of the several on this subject recently published that have added knowledge to the problems of peripheral circulation. From the clinical point of view colorimetry is too time-consuming to be of use in the wards, yet a few cases studied by this and other methods undoubtedly lead to a better understanding of the peripheral and generalised arterial diseases.—F. A. R. Stammers.

ANATOMY. Regional and Applied. By R. J. Last, M.B. (Adel.), F.R.C.S., Professor of Applied Anatomy, Royal College of Surgeons of England. 10 × 7in. Pp. xii + 665, with 309 figures, many in colour. Index. 1954. London: J. & A. Churchill Ltd. Price 55s.

Those who have heard Professor Last lecture, or who are conversant with his original work and published articles, would expect that any book he wrote on Regional and Applied Anatomy would be well worth reading—and this book is well worth reading. It does not follow the normal pattern of anatomy text-books. Probably the key to its conception lies in the experience of its author. Professor Last spent many years with that master human and comparative anatomist, Wood Jones. He practised surgery for twenty years and, more recently, has taught postgraduate anatomy. Consequently the body is to him not an inert cadaver to dissect for topographical information, but a living organism, the form and working of which he explains sometimes on a phylogenetic, sometimes on an embryological and sometimes on a physiological basis, and occasionally from the point of view of a surgeon. Thereby the reader is provided with numerous pegs on which to hang his knowledge; and finds many parallel approaches, which simplify the understanding of the part and yet emphasise the cohesion of the whole.

The first part of the book consists of an account of the tissues and structures that make up the body, some general considerations of the nervous system and embryology. Thereafter, instead of having the systems described in sequence, the regions of the body are taken one by one *in toto*, so that a comprehensive picture of any given region is easy to obtain.

The numerous illustrations are of a high order and are well reproduced. Many of the line and wash drawings come from the author's hand, and show with great clarity the salient features required.

As Professor Last explains in his preface, the scope of the book is not encyclopaedic. A specialist may find the minute description of some structure in his region to be absent. For example, orthopaedic surgeons will find no mention of the abnormal forms and insertions of the tendon of the tibialis anterior muscle, which may contribute to certain foot deformities; nor will they find reference to the extensive blood supply of the tensor fasciae latae muscle which is important in some transplants of this muscle. Nevertheless, this fresh and pleasantly written book is an outstanding achievement, and postgraduates particularly, once they have read it, will not part with it. They will soon realise that its modest cost is a very profitable investment.—Robert I. Stirling.

ATLAS OF THE SKELETAL DEVELOPMENT OF THE RAT (Long-Evans Strain). Normal and Hypophysectomized. By Hermann Becks, M.D., D.D.S., F.A.C.D., Professor of Dental Medicine, The George Williams Hooper Foundation for Medical Research, College of Dentistry, and Research Associate, Institute of Experimental Biology, University of California; and Herbert M. Evans, M.D., Sc.D., Docteur, honoris causa (San Marcus, Paris), Professor of Anatomy, Hertzstein Professor of Biology, Director, Institute of Experimental Biology, University of California. With the Technical Assistance of Mrs Joyce Haas, Dental Reontgenologist, Berkeley, California. Volumes I and II. 9 × 11 in. Vol. I, pp. xxxv + 65, totally comprising of figures and 4 tables. Volume II, pp. xiii + 78, totally comprising of figures and 5 tables. 1953. 300 copies of this Atlas were prepared at San Francisco by The American Institute of Dental Medicine. Price $48.

One of the outstanding landmarks in our knowledge of the relationship of hypophysial [pituitary] function and growth was the experimental production by Evans and Long of giantism

in rats by the daily intraperitoneal administration of an alkaline extract of hypophysis [pituitary gland]. Clinical studies had already indicated such a relationship, and the experimental work of Aschner and of Cushing had shown that in puppies removal of the hypophysis caused dwarfism: the experiments of Evans and Long, however, were final proof that a chemical substance produced by the hypophysis was concerned in growth. This substance, which a number of workers have since prepared in highly purified form, is usually referred to as "pituitary growth hormone." Since the discovery of growth hormone, Evans and his colleagues, working at the Institute of Experimental Biology at the University of California, have produced a long and interesting series of papers (recently summarised by Simpson, Asling and Evans) on the effects of various hormones, including pituitary growth hormone, pituitary adrenocorticotrophic hormone and thyroxin, on growth. Quite early in their work, they found that in the rat the proliferating cartilage of the epiphysial plate of a long bone was a very convenient site for the study of structural aspects of normal or abnormal growth. They showed that the thickness, for example, changed with alterations

FIG. 1A
Radiograph of a normal rat aged fifty-six days.

FIG. 1B
Radiograph of a rat aged fifty-six days, hypophysis removed at age of twenty-eight days.

(Both illustrations have been reduced by a half.)

in growth rate; the faster the animal grew, the thicker was the epiphysial plate. These findings formed the basis of the so-called "tibia" test for assay of pituitary growth hormone.

A number of papers of Evans and his colleagues deal with the effects of hypophysectomy on the structure of the growing regions of the skeleton, and these papers are now amplified by the publication of the present atlas, *The Skeletal Development of the Rat*, by Becks and Evans. This book illustrates in great detail the radiological and histological appearance of the skeleton of normal female rats from the age of one day to about three and a half years. Similar information is provided for female rats hypophysectomised at twenty-eight days of age and studied for periods up to 421 days. All the rats belonged to the Long-Evans strain which was developed in the Department of Anatomy in the University of California from the progeny of an albino female rat mated with a wild grey male rat.

The atlas, which has been beautifully produced, should be esteemed as much a work of art as a scientific record. As a work of art it is superb. All the illustrations, both radiographs and photomicrographs, are individually produced photographic prints, and they are uniformly excellent. Radiographs include whole skeletons and individual bones, and histological preparations are shown

from the tibia, femur, third metacarpal, humerus, third rib, ninth caudal vertebra, skull, mandible and teeth.

All these preparations illustrate very clearly the general retardation of skeletal growth in the hypophysectomised animals, as well as the retardation of normal skeletal maturation which is shown by the failure of fusion of certain epiphysial centres of ossification. The atlas provides the most fully documented information on the skeleton of the rat that is available in published form. The investigator, however, must remember two points in connection with the information it contains. Firstly, its findings relate to a rather special variety—the Long-Evans strain—of rat, and we do not know whether differences of skeletal growth and maturation exist between this strain and the more commonly used albino Wistar rats of most laboratories. Secondly, the pictorial material which makes up the atlas represents a small selection from a very much larger bulk of radiological and histological data. It is put forward as "typical" of whatever feature has been chosen for illustration, but it is not possible to assess the range of variation encountered in the groups of animals from which the selected illustrations have been taken. In the opinion of the reviewer, this second point is a serious disadvantage, but in spite of it the atlas will most certainly be treasured by those fortunate enough to be able to afford a copy.—H. A. Sissons.

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FLUID BALANCE IN SURGICAL PRACTICE. By L. P. Le Quesne, M.A., B.M. (Oxon.), F.R.C.S. (Eng.), Assistant Director, Department of Surgical Studies, Middlesex Hospital. 9 × 6 in. Pp. vii + 130, with 41 figures. Index. 1954. London: Lloyd-Luke (Medical Books) Ltd. Price 17s. 6d.

This monograph is based on the Moynihan Prize Essay for 1953, delivered at the Royal College of Surgeons. The author does not waste space on abstruse discussion: the work deals in a clear and concise way with a most interesting and difficult subject, and provides a large amount of information of great value in the day-to-day care of patients. There are many clear diagrams, and a long list of references for those having occasion to go more deeply into any special part of the subject. The introduction of certain relatively new terms and units of measurement, e.g., milli-equivalents and milli-osmols, will evoke a sigh from older clinicians, and an inevitable bow to the march of progress. The book should be of great help to all those who are confronted with the perplexing problems of fluid balance in surgical practice.—J. C. Scott.

MALADIES DES OS ET DES ARTICULATIONS. By Stanislas de Sèze, Professeur agrégé à la Faculté de Médecine de Paris, Médecin de l'Hôpital Lariboisière and Antoine Ryckewaert, Médecin-Assistant des Hôpitaux de Paris. 10 × 7¼ in. Weight 8 lb. 2 oz. Pp. 1,218, with 391 figures. Index. 1954. Paris: Editions Médicales Flammarion. Price 9,300 F. fr.

This addition to the rapidly growing series of loose-leaf medical books from the House of Flammarion will be welcomed by all orthopaedic surgeons who can read French. It is not an ordinary orthopaedic text-book because many of the standard problems, such as those of reconstructive surgery, are not touched. Described as dealing with diseases of bones and joints, it is in fact a comprehensive encyclopaedia of every known disease affecting these structures, the rare receiving equal consideration with the common—not one is missed. The same approach is followed for each: a brief historical introduction, incidence, pathological anatomy, symptomatology, course and treatment. The information is succinct and up to date, and the book forms a ready reference for anyone seeking the latest views about common complaints like rheumatoid arthritis

and Paget's disease, or what is known about rarities such as cadmium intoxication, cystinosis or Brucella spondylitis. The references at the end of each section are not intended to be comprehensive, but they list most of the principal papers with a natural bias towards French authors. The illustrations are beautifully reproduced and have been selected with care; the only complaint is that there are not more of them. This is, indeed, a monumental work and, if the same standard is maintained with the promised annual additions, it will remain of lasting value.—Philip Wiles.

RECONSTRUCTION SURGERY AND TRAUMATOLOGY. Edited by M. Lange, with twenty other contributors. Vols. I and II. 10 × 7¼ in. Vol. I, pp. 262, with many figures. 1953. Vol. II, pp. 244, with many figures. 1954. Basel/New York: S. Karger. Price per volume Sw. fr. 36.

The first two volumes on reconstructive surgery have been launched by the publishing house of Karger. Their aim is to make available a record of progress in the entire field of reconstructive surgery of the locomotor system as an international year book.

The first volume deals with three subjects. Intramedullary nailing of fractures is described in all its aspects by four authors, one of whom is Küntscher himself. The problem of aseptic necrosis of the head of the femur after nailing for fracture of the neck of femur is discussed by six authors in separate chapters. The final section of this volume is devoted to the treatment of irreparable nerve palsies and includes chapters on median, ulnar and radial palsies and one on poliomyelitis affecting the hand.

The second volume is divided into three main sections. Repair of the cut flexor in the wrist, hand and particularly in the finger is discussed from every angle by four authors. There are four chapters on the treatment of fractures of the carpal scaphoid bone and non-union. The last part of this volume is devoted to hare lip and some simple plastic procedures.

Although most of the twenty-six chapters are written in German, there are two in French and four in English. At the end of each article is a brief summary in all three languages. Unfortunately, some of the summaries only state what the article is about, but most include the author's main conclusions.

There is no doubt that these beautifully produced and well illustrated books contain the latest and most authoritative views on the subjects presented and should be in the library of every consultant dealing mainly with the surgery of trauma.—L. W. Plewes.

ATLAS UNFALLCHIRURGISCHER OPERATIONEN. By Otto Russe. 9 × 11¾ in. Pp. xii + 106, with 48 full page plates. 1955. Wien-Bonn: Verlag für Medizinische Wissenschaften Wilhelm Maudrich. Price 87s. 6d.

If a skilled surgeon with a lively temperament and extensive experience and an ingenious turn of mind writes of his own practice, the reader may reasonably expect the result to be practical, interesting and instructive. *An Atlas of Operations for Trauma* by Otto Russe certainly fulfils such an expectation.

The information it sets out to convey is presented in a novel and attractive manner. On each right page are clear simple semi-diagrammatic sketches and equally clear photographs: on each left page these are explained by brief but ample notes in three languages. The German version is followed by a complete translation in very good English, and below that a similar translation in what I judge to be very good French. Besides being useful surgically the text is therefore quite useful linguistically. In fact the illustrations are so clear as to be almost self explanatory, and the text, while concise, is still lucid and very much to the point. The general impression is as if the author were saying, "This is what I do; if you like it, try it; I have found it helpful. If you do not like it, well . . ."

A comprehensive field of traumatic surgery is dealt with on an anatomical pattern and in many of the more important regions alternative methods are described. In the spine for example there are several types of bone grafts, in the hip several arthroplasties; and for non-union in long bones several types of bone grafts are suggested. The author's own method of grafting an ununited fracture of the carpal scaphoid is clearly described, and looks so attractive that one almost regretted being rather disillusioned about grafting scaphoids. No metal is used either in this procedure or in some of the bone-grafts, and this is surprising in view of the fairly free use of metal in general. I thought the reconstructive surgery of the head of the radius ingenious but a little fiddling and

unpractical. It is difficult to see why so much trouble should be taken and so many risks incurred to preserve the head of the radius.

In only one point did the text and illustrations not make the meaning immediately clear. This is on page 94 (diagram A) and refers to compound oblique fracture of the tibia and fibula. In a personal communication the author, to whom I had written for clarification, agreed that in the second line of the English version the word " sling " should be " loop " and went on to explain that the 3-millimetre pin which is illustrated as being " temporarily " inserted was withdrawn immediately after the wire loop had been tightened over it. In other words the pin (or perhaps one might say " bent rod ") was used merely to ensure uniform looseness of the slings. The interest I have displayed must not be taken to suggest that I like the method; I was merely anxious to be sure that my dislike was correctly applied. Anyone interested to know what all this is about would do well to get a copy. He will find plenty else to interest him. The fact that in an extensive work of this nature only such small points can be criticised is in itself a criterion of the high standard and interest which is achieved.—Bryan McFarland.

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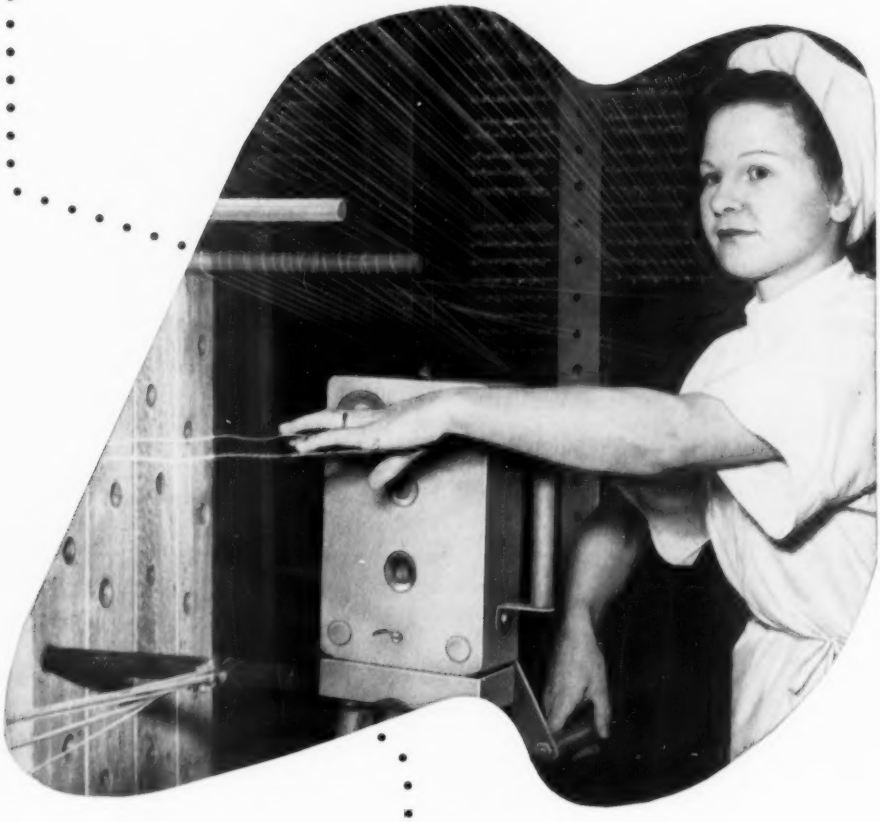

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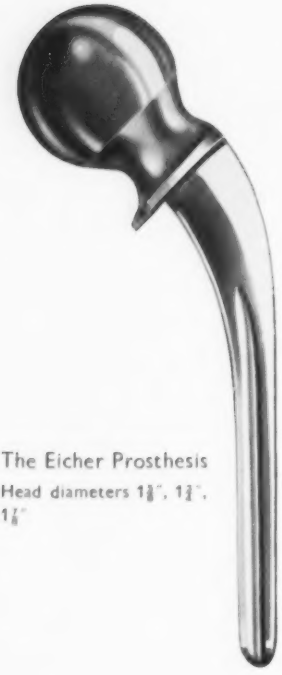

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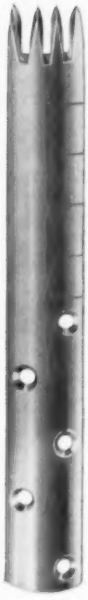

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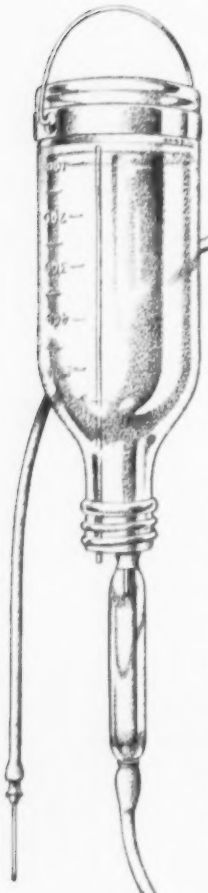

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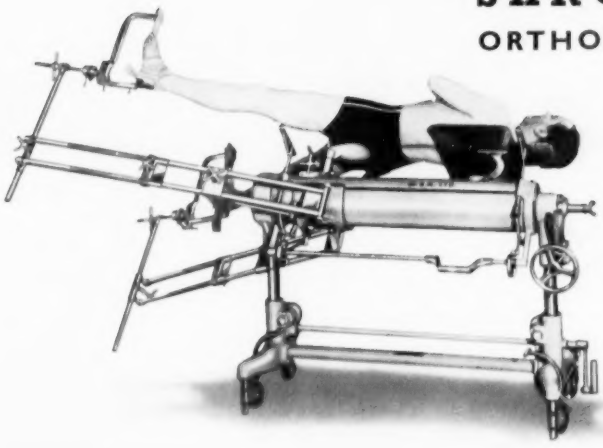

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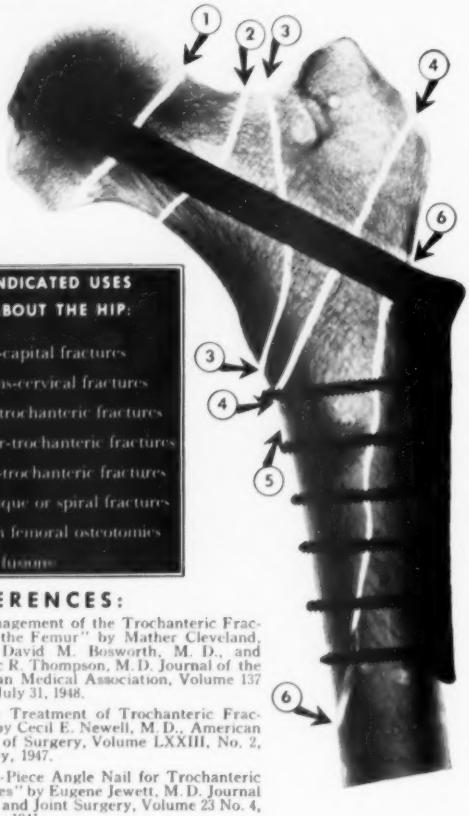

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* 1. "Management of the Trochanteric Fracture of the Femur" by Mather Cleveland, M. D., David M. Bosworth, M. D., and Frederic R. Thompson, M.D. Journal of the American Medical Association, Volume 137 No. 14, July 31, 1948.

2. "The Treatment of Trochanteric Fractures" by Cecil E. Newell, M.D., American Journal of Surgery, Volume LXXIII, No. 2, February, 1947.

3. "One-Piece Angle Nail for Trochanteric Fractures" by Eugene Jewett, M.D. Journal of Bone and Joint Surgery, Volume 23 No. 4, October, 1941.

4. "The Treatment of Intertrochanteric Fractures of the Femur" by Walter G. Stuck, M.D. Surgery, Volume 15 No. 2, February, 1944.

5. "Introchanteric Fractures of the Femur" by Mather Cleveland, M.D., David M. Bosworth, M. D. and Frederic R. Thompson, M.D. The Journal of Bone and Joint Surgery, Volume 29 No. 4, October, 1947.

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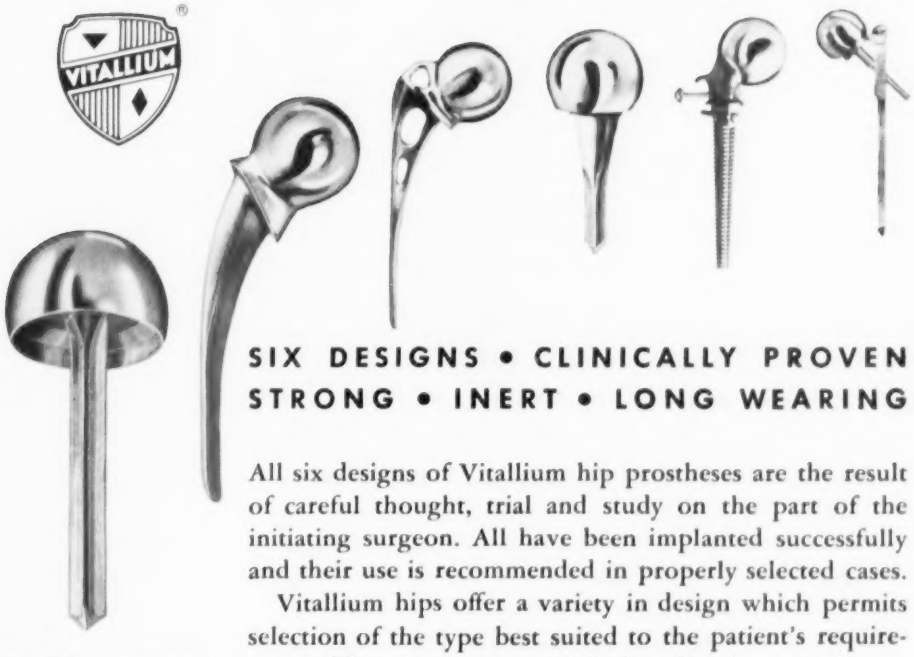

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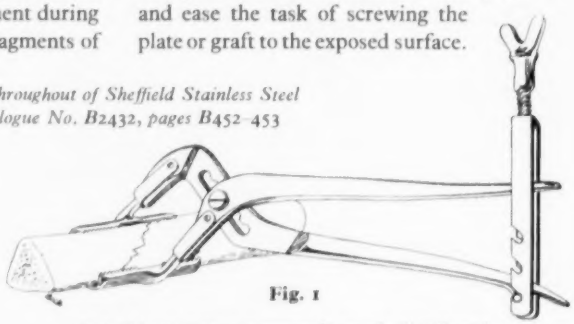

Fig. 1

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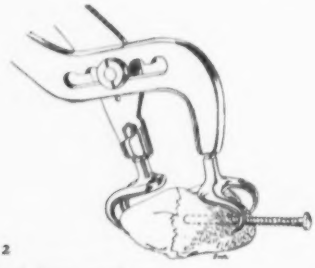
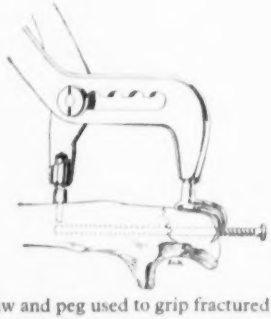


Fig. 2
Hooked jaws used to grip a fractured patella.



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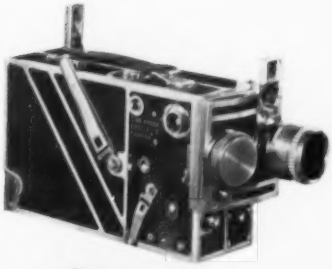

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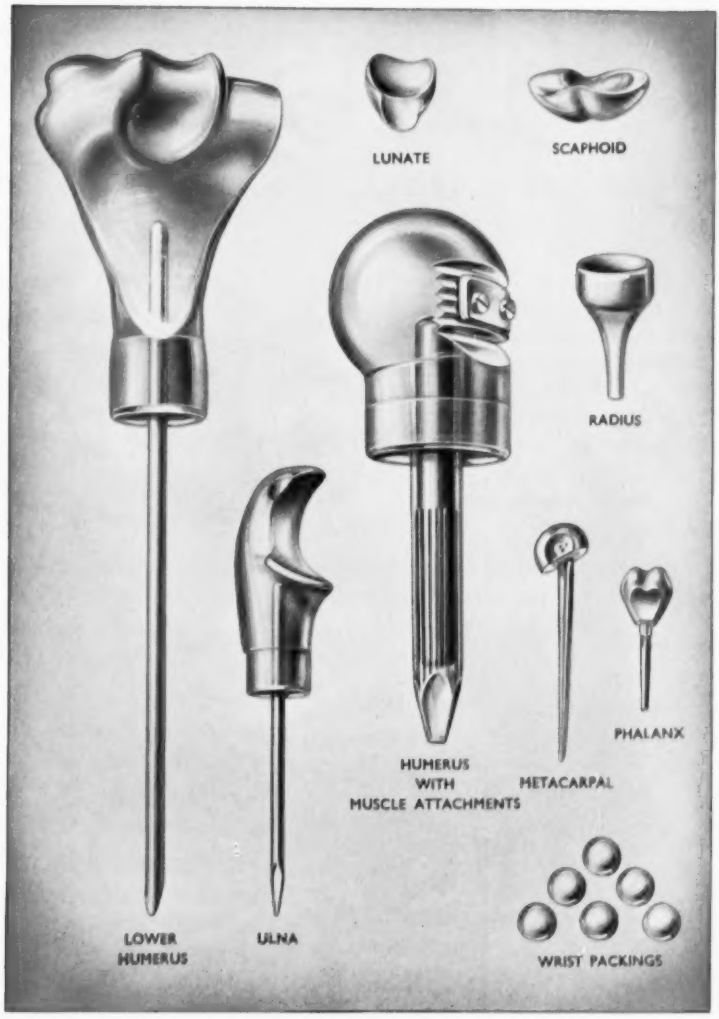

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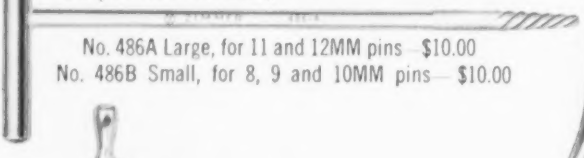

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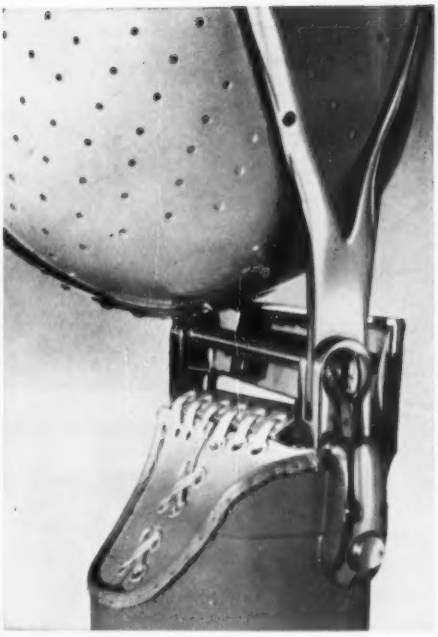

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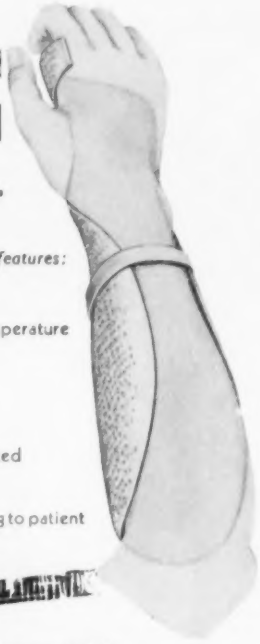

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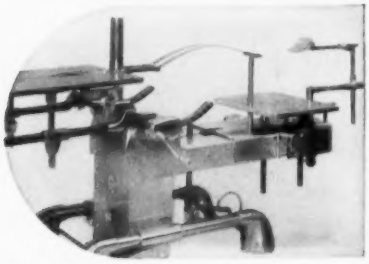

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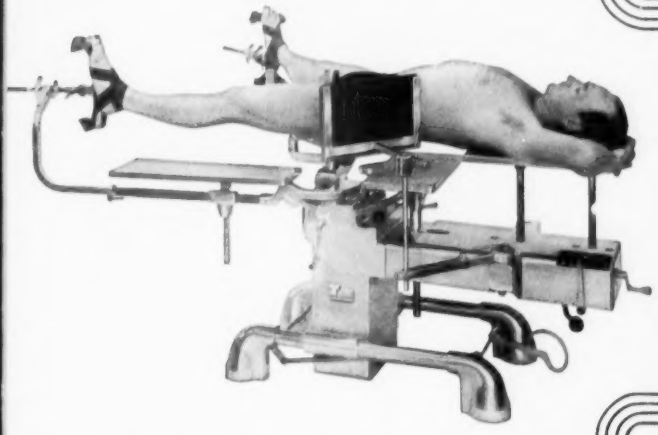

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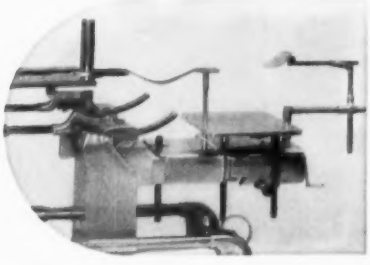

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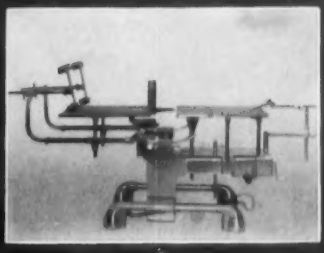

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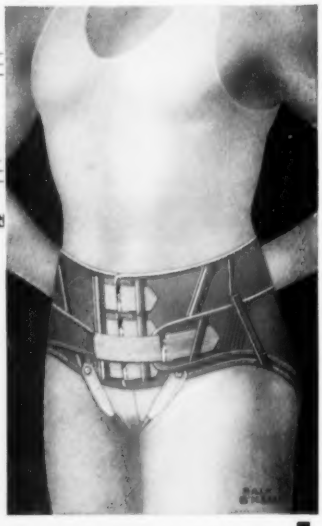

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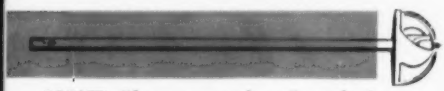

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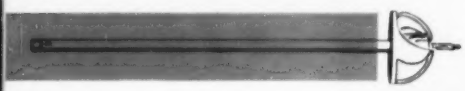

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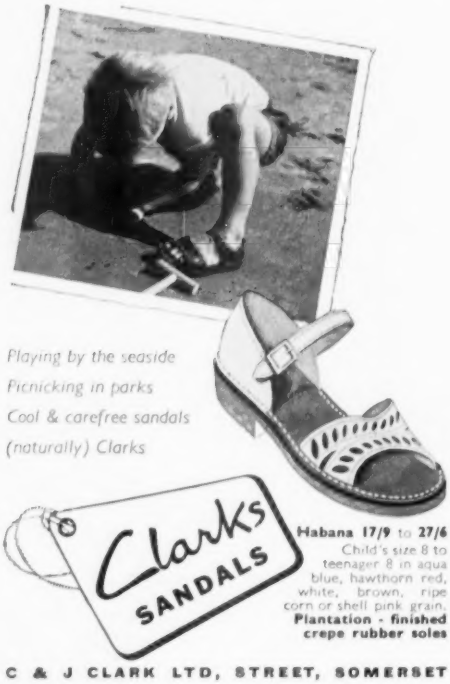

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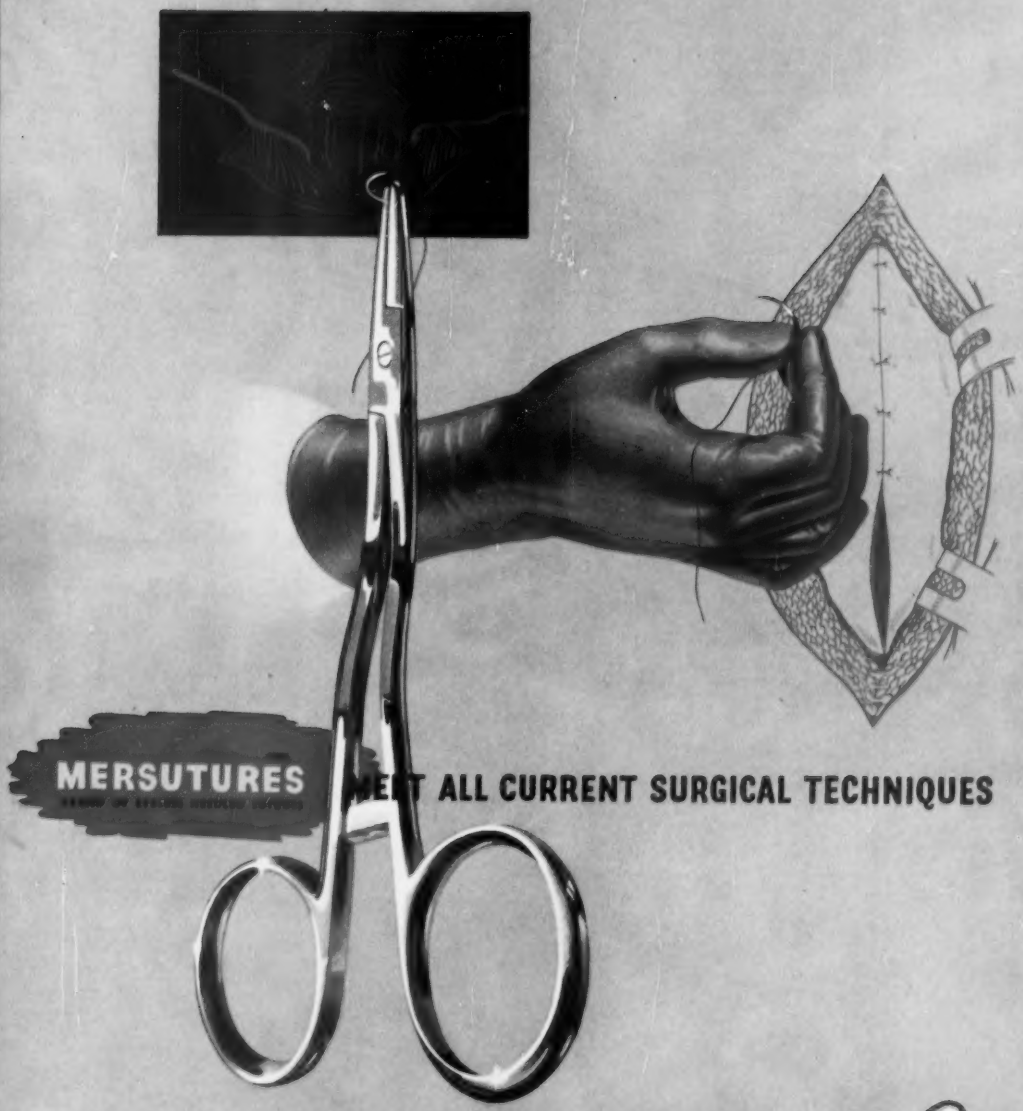

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